A-Train Symposium, New Orleans, La, 27 October 2010

Use of A-Train data for Aerosol Validation and Assimilation in the ECMWF Integrated Forecast System

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- ECMWF for its operational analyses and forecasts ingests gigabytes of observational data every day (including **AIRS, AMSU, AMSR-E, MODIS wind**) and produces weather forecast of temperature, humidity, wind, ..
- Recently, with the EU FP7 **GEMS** then **MACC** projects, ECMWF has been producing experimental analyses and forecasts of reactive gases, greenhouse gases, and aerosols.
- This presentation quickly surveys some recent and ongoing work dedicated to **aerosols**.
- A-Train data (CloudSat/CALIPSO) data are also used in some experimental cloud analysis (S. Di Michele's poster).

- GEMS: Global and regional Earth system Monitoring using Satellite and in-situ data;
- MACC: Monitoring Atmospheric composition and Climate

GMES Atmosphere Component Service

- **Part of Europe's Global Monitoring for Environment and Security initiative**
  - **development of operational space-based observation**
  - **strengthening of complementary in-situ observing systems**
  - **development and operation of services, based on core integrated assimilation and forecasting**
  - **three environmental services for Land, Ocean and Atmosphere**

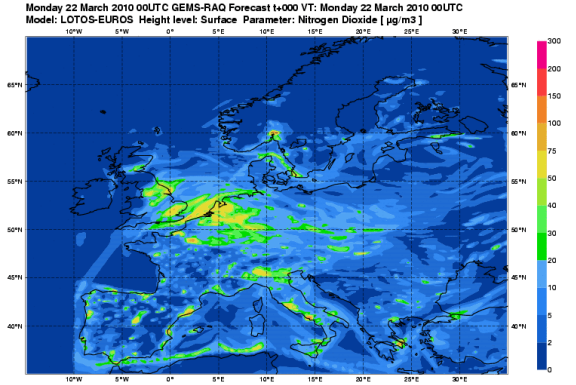
- **A 32-partner EC project called GEMS (Global and regional Earth-system Monitoring using Satellite and in-situ data)**
  - **developed systems for the core GMES atmospheric service**
  - **May 2005-May 2009, status completed**

- **A 48-partner EC-funded project called MACC:**
  - **provides pilot GMES Atmosphere Component Service**
  - **succeeds earlier projects GEMS and PROMOTE**
  - **coordinated by ECMWF**
  - **started in June 2009, scheduled to end October 2011**

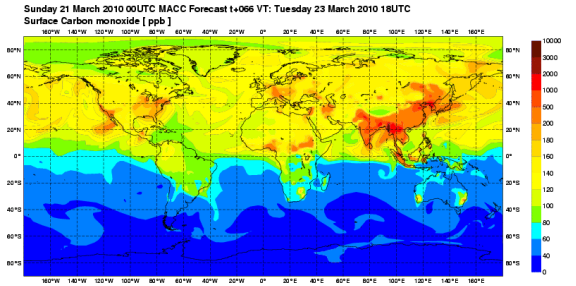
MACC Daily Service Provision

http://www.gmes-atmosphere.eu

Air quality

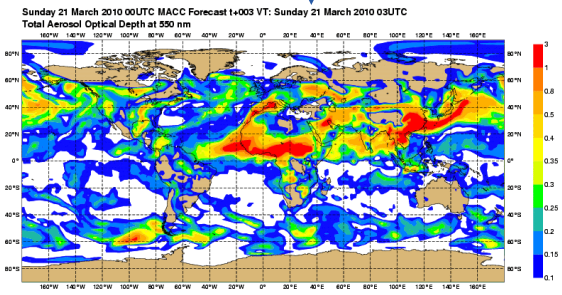


Global Pollution

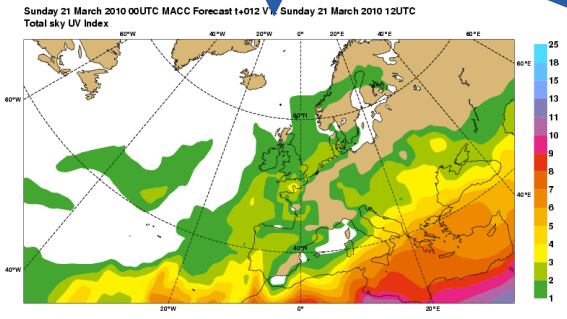


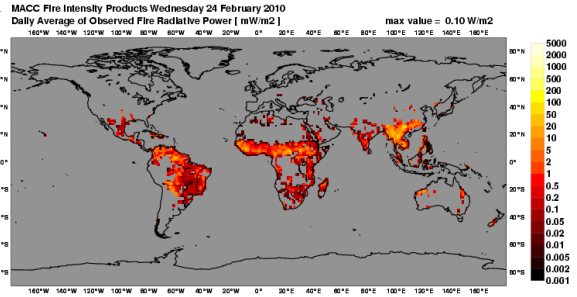
Biomass burning

Aerosol



UV index





(1) Quick overview of the MACC/ECMWF aerosol analysis and forecasting system

Forward model

12 aerosol-related prognostic variables:
* 3 bins of sea-salt (0.03 – 0.5 – 0.9 – 20 μm)
* 3 bins of dust (0.03 – 0.55 – 0.9 – 20 μm)
* Black carbon (hydrophilic and –phobic)
* Organic carbon (hydrophilic and –phobic)
* SO_2 -> SO_4

Physical processes include:

•emission sources (some of which updated in NRT, i.e.fires),
•horizontal and vertical advection by dynamics,
•vertical advection by vertical diffusion and convection
•aerosols are externally mixed
•aerosol specific parameterizations for dry deposition, sedimentation, wet deposition by large-scale and convective precipitation, and hygroscopicity (SS, OM, BC, SU)

Morcrette et al., 2009, JGR

Analysis

Integrated in the ECMWF incremental 4D-Var

Control variable is formulated in terms of the total aerosol mixing ratio. Soon to come: fine and coarse mode. Increments in total mass are repartitioned into the single species according to their fractional contribution to the total.

Background error statistics have been computed using forecasts errors as in the NMC method (48h-24h forecast differences).

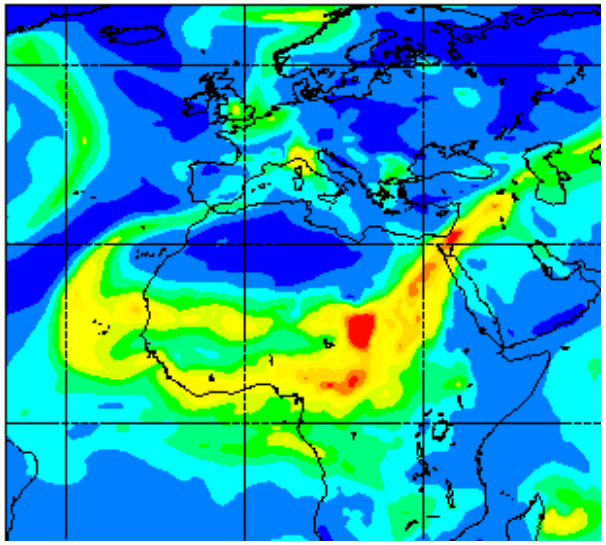
Assimilated observations are the MODIS Aerosol Optical Depths (AODs) at 550 nm over land and ocean. Observation errors are prescribed fixed values as a result of investigation to implement the variational bias correction (not active).

Benedetti et al., 2009, JGR

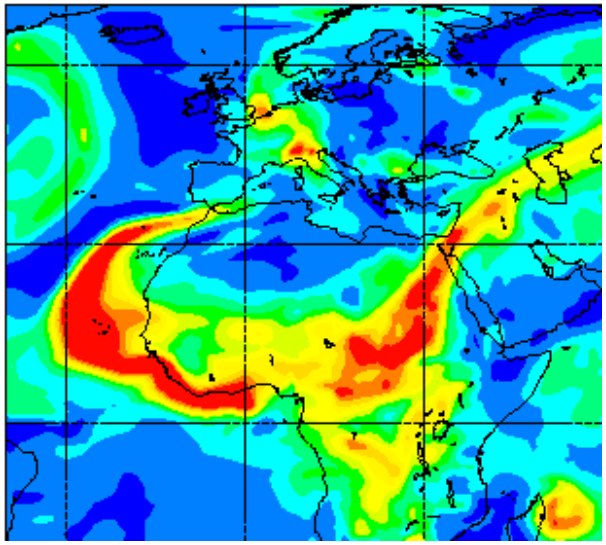
(2) Evaluation with MODIS/SEVERI and AERONET

Saharan dust outbreak: 6 March 2004

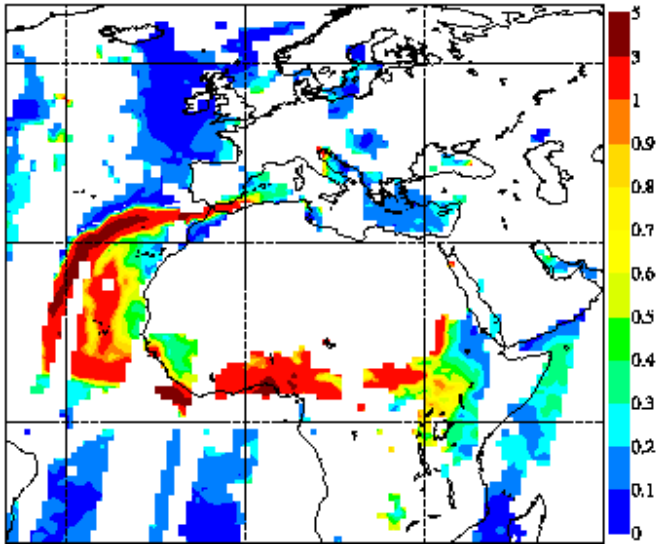
Model simulation



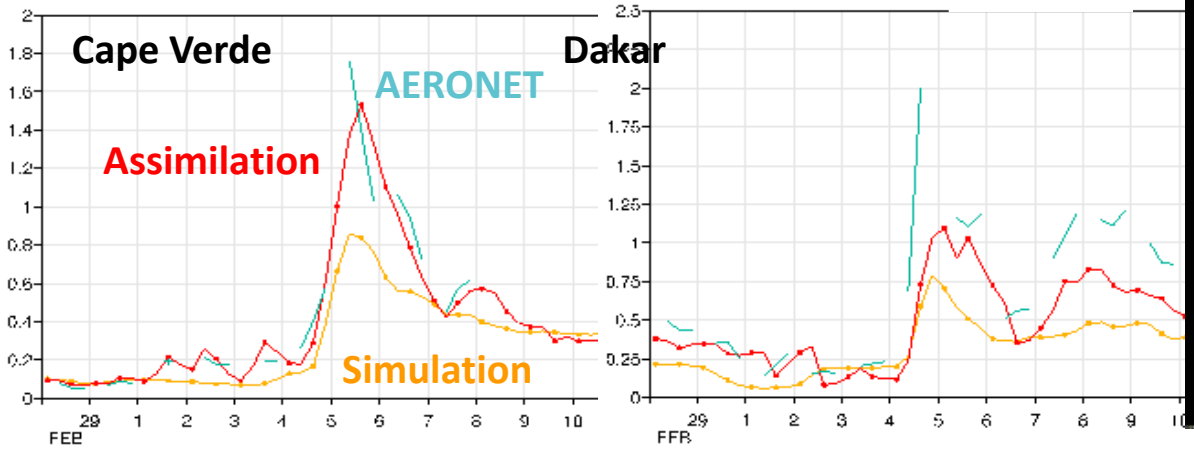
Assimilation

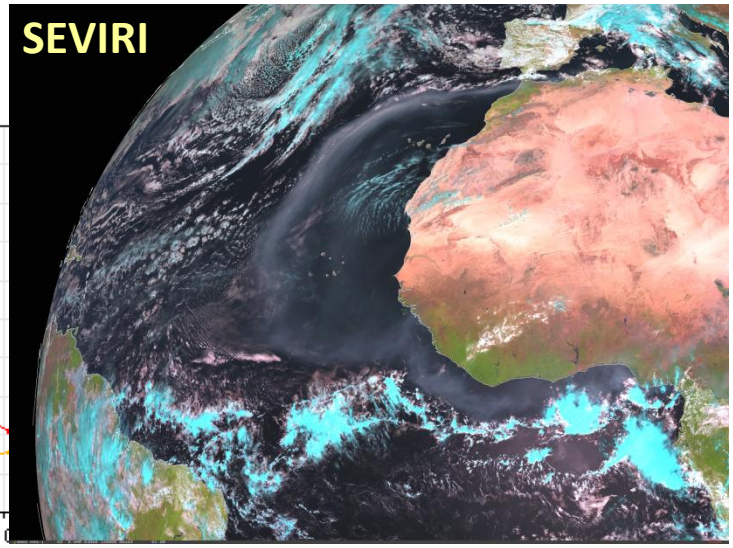


MODIS



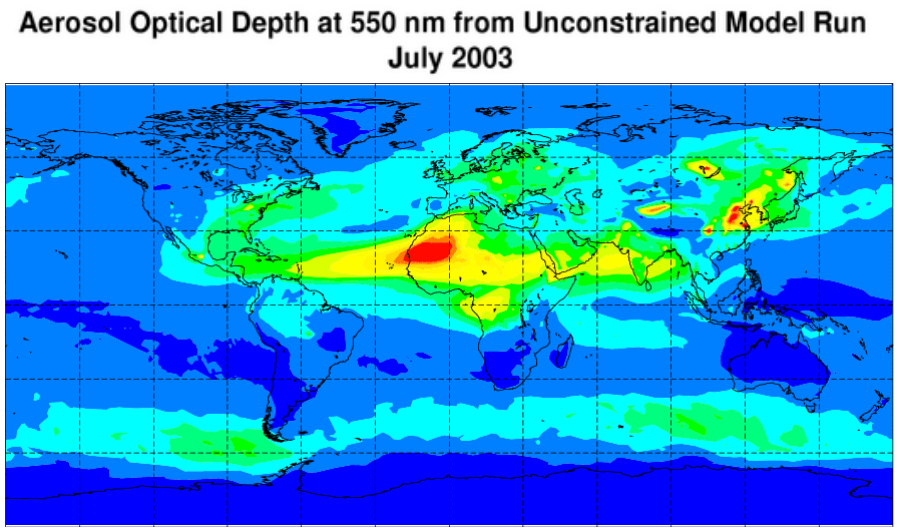
Aerosol optical depth at 550nm (upper) and 670/675nm (lower)

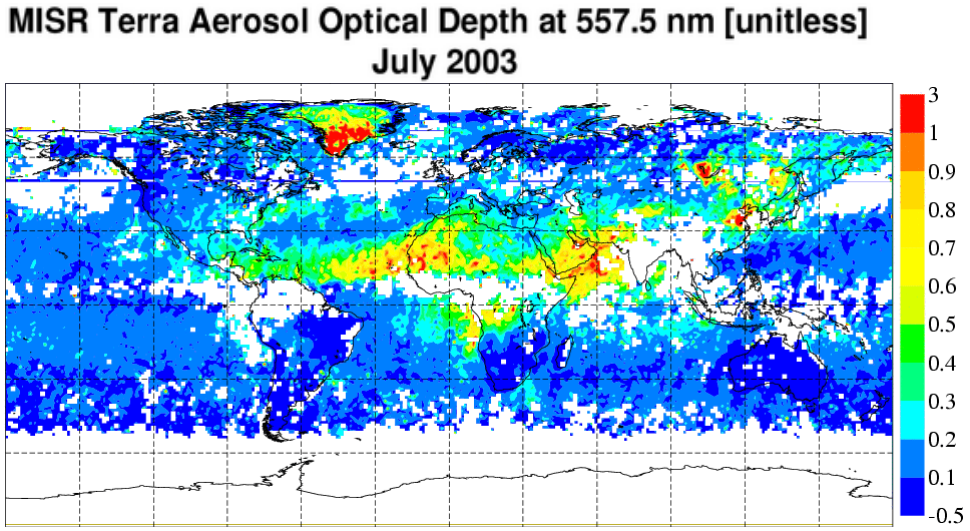


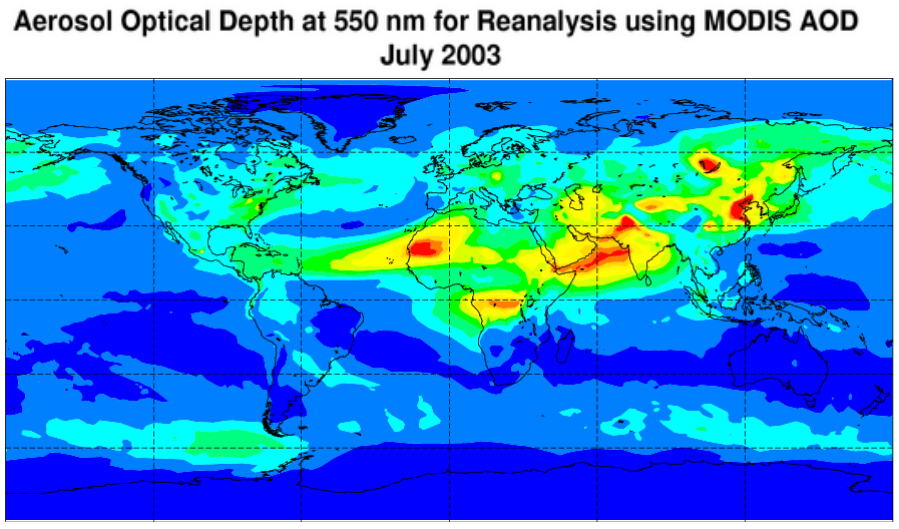


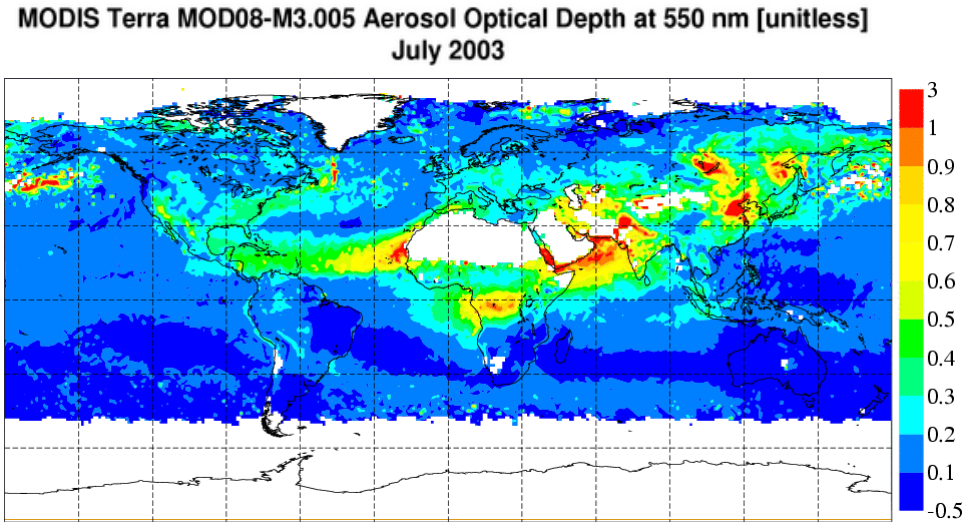
Morcrette et al., 2009; Benedetti et al., 2009

(2) Comparison of GEMS simulated and analysed aerosol optical depth with MODIS and MISR for July 2003



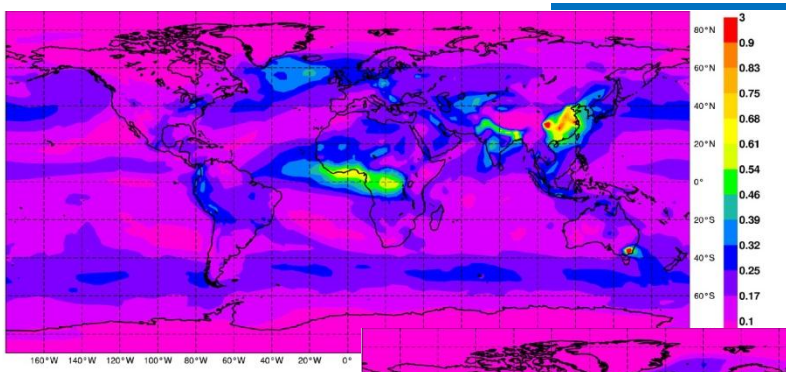






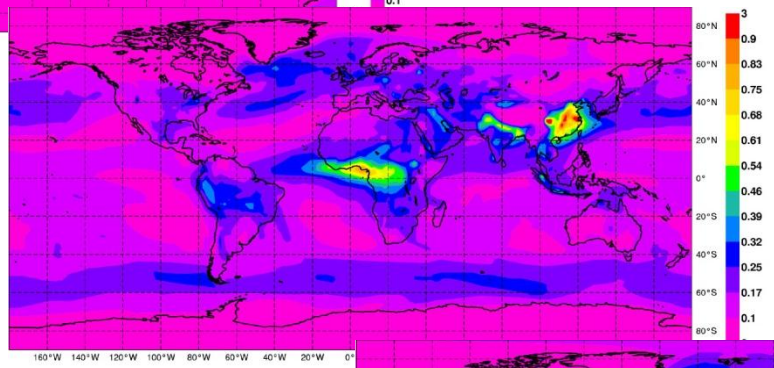
Morcrette et al., 2009; Benedetti et al., 2009

Total aerosol optical depth

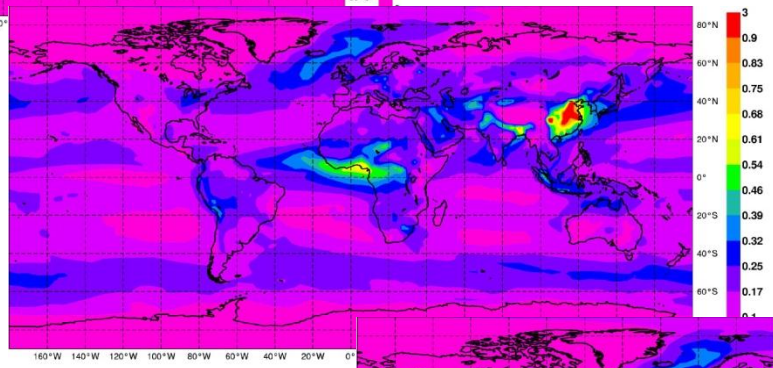


January 2003

- January 2003: increased AOD over south-eastern Australia as a result of bush fires

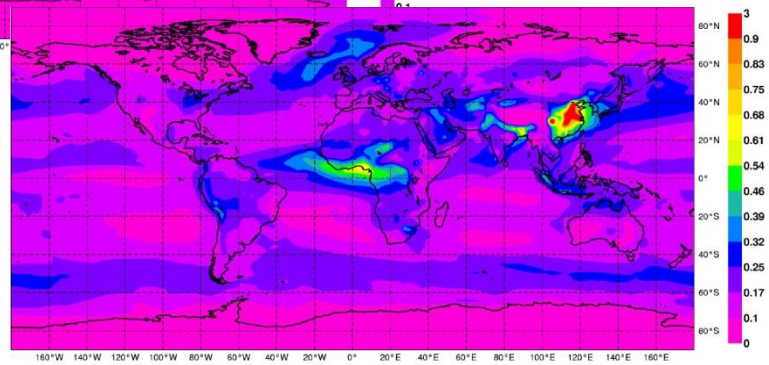


2004



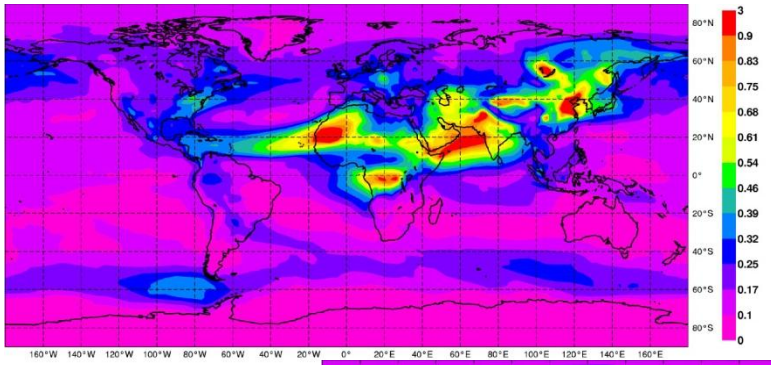
2005

- Low AOD-month with just a few hot spots (India, China and West Africa).
- Strip of large AOD at the foot of the Himalaya is a constant feature, due to trapped pollution coming from the Indian sub-continent.
- Large values of AOD with little seasonal and inter-annual variability over China, associated with anthropogenic pollution.
- Winter AOD maximum of varying inter-annual strength off the coast of West Africa at the Equator associated with biomass burning of the tropical savannah



2006

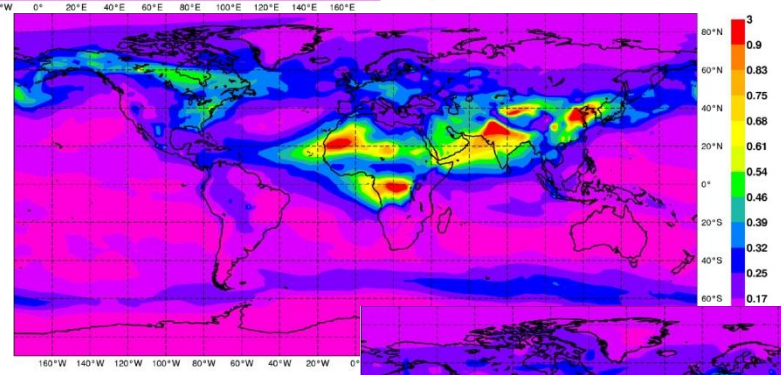
Total aerosol optical depth



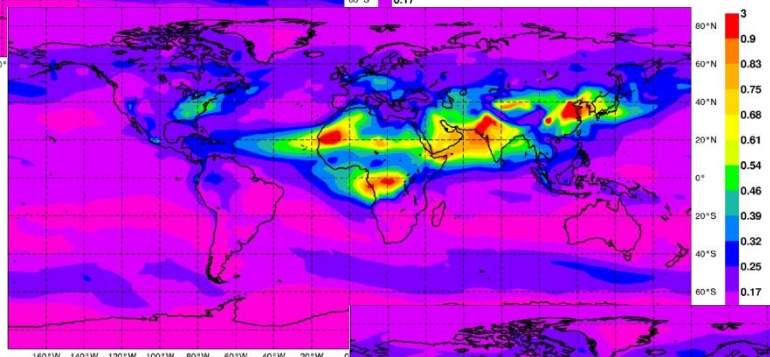
- **July 2003: AOD maxima over Siberia associated with wild fires. This signature is also present in the CO field which is independently analyzed.**

- **July 2004: presence of a large aerosol load in the North-West of America connected with pollution transport from East Asia.**

July 2003



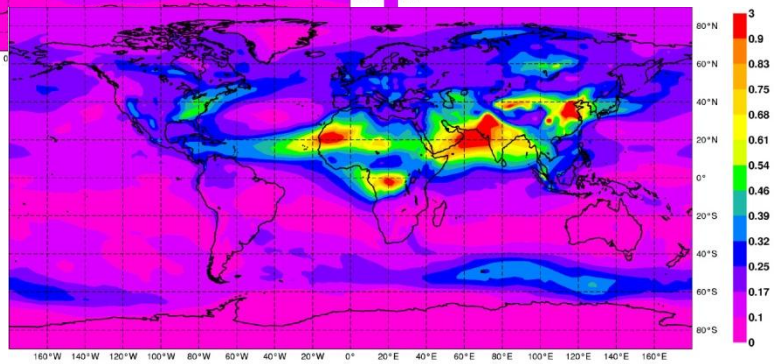
2004



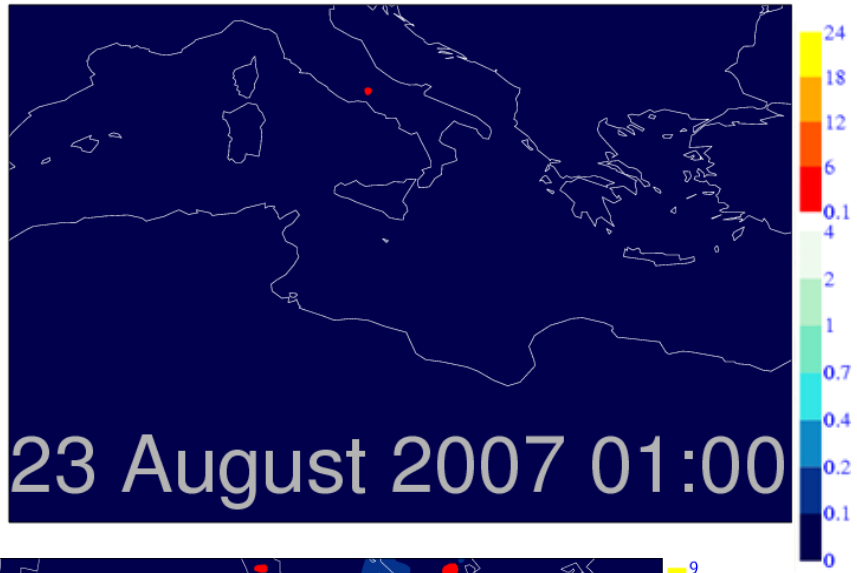
2005

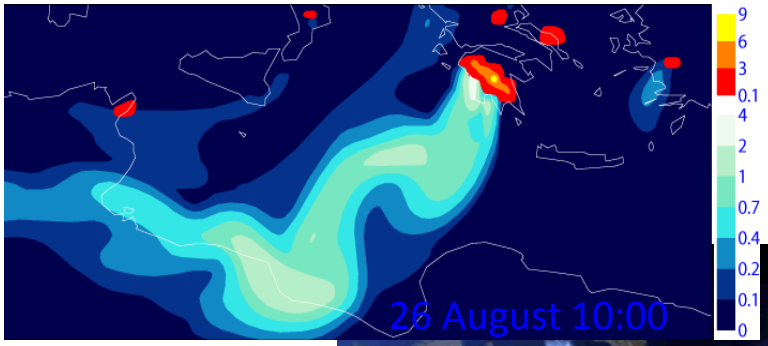
- **Biomass burning over West Africa and desert dust emissions from the Sahara are the main "constant" features**
- **Aerosol load in the Indian Ocean associated to strength of the monsoon**
- **The winter hemisphere usually presents larger values of AOD over the oceans connected to more intense circulation and increased production of maritime aerosols with inter-annual variability dependent on that of wind intensity at the ocean surface.**

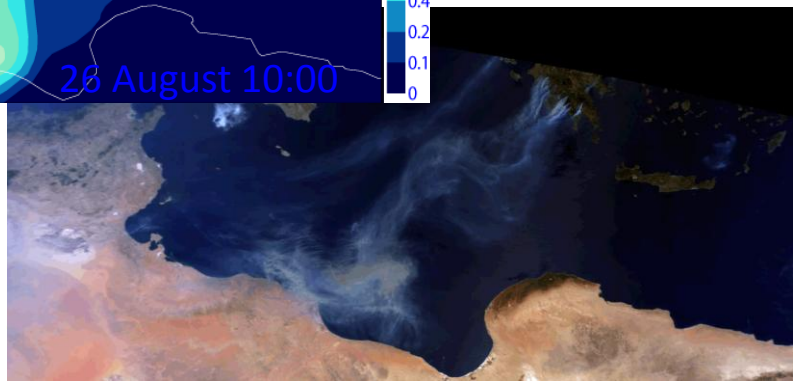
2006



(2) Evaluation with SEVERI - Case study: Fire emissions in August 2007



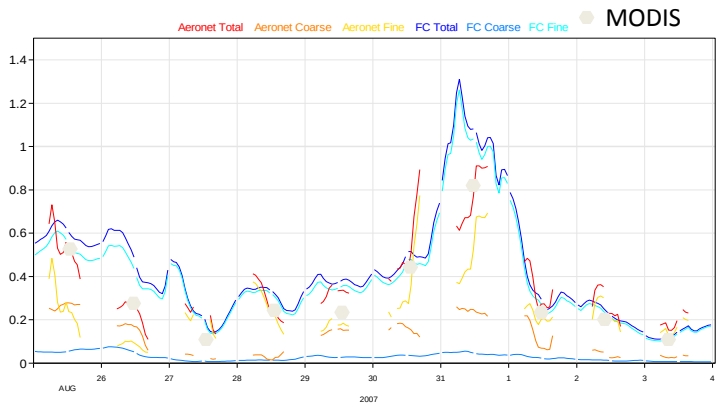




Observed Fire Radiative Power (originally from SEVIRI over the Meteosat disk and MODIS elsewhere) is converted to emitted aerosol.

Run at 25km global resolution rather than 125km standard GEMS global resolution.

Joint work with FREEVAL project (M. Wooster, G. van der Werf, …).



J.W. Kaiser et al., 2009

Sydney dust storm, 23-09-09

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NEWS LIVE BBC NEWS CHANNEL

News Front Page

Page last updated at 10:42 GMT, Wednesday, 23 September

Desert dust storm chokes Sydney

Sydney's red dust has been blown from the outback

A large stretch of Australia's east coast, including the largest city Sydney, has been shrouded in red dust blown in from the desert outback.

Visibility in Sydney was so bad that flights were diverted and harbour ferry traffic disrupted.

ABC News

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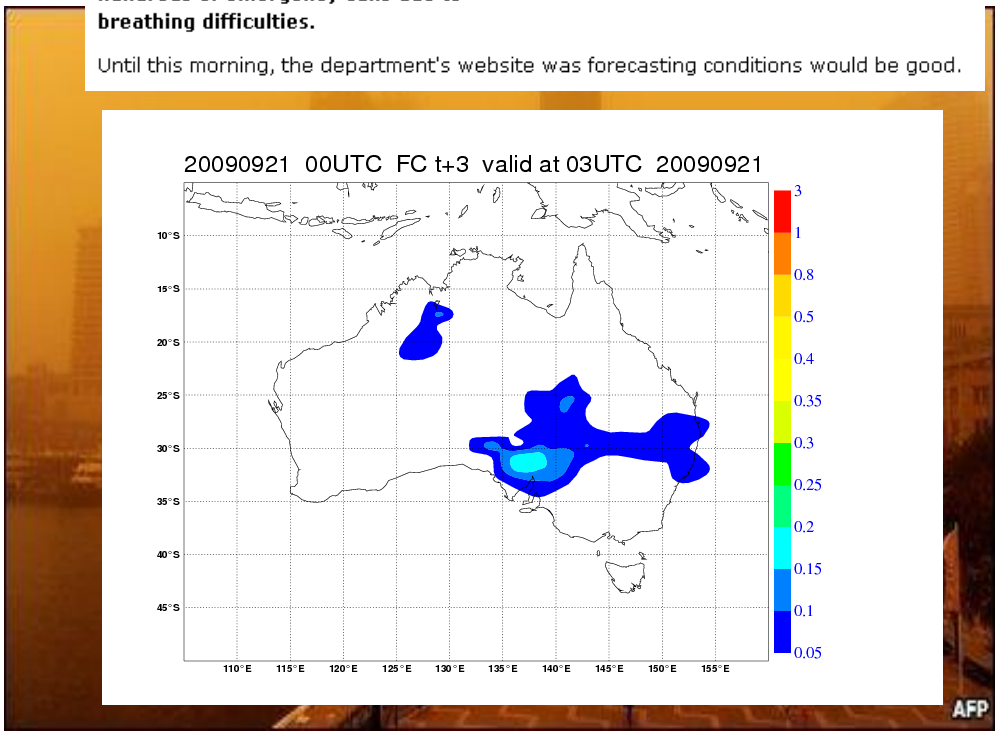
Dept admits error in air quality forecast

Posted 11 hours 54 minutes ago
Updated 11 hours 51 minutes ago

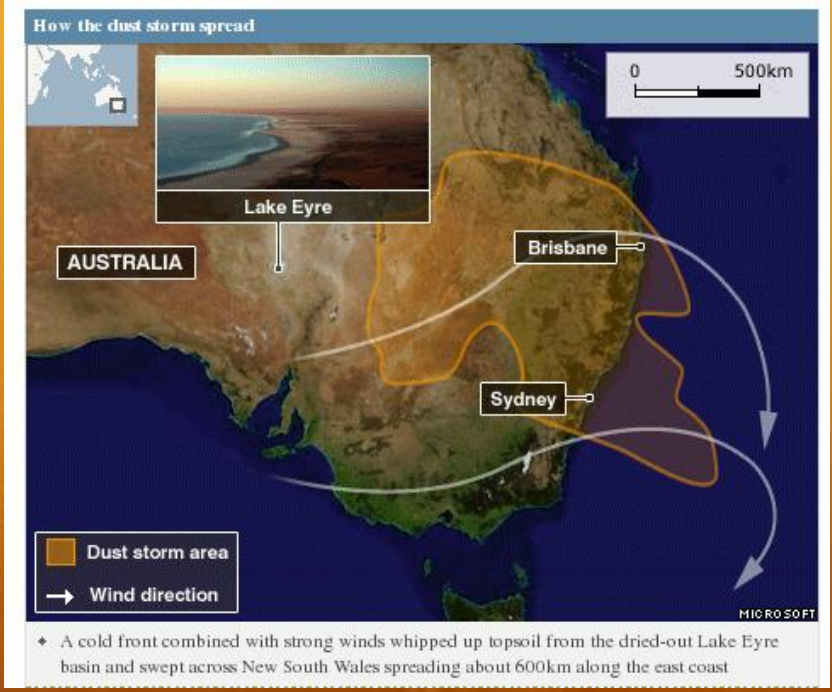
The New South Wales Environment Department has admitted its forecast for air quality in Sydney today was wildly wrong after a dust storm prompted hundreds of emergency calls due to breathing difficulties.

Audio: Respiratory expert Dr Christine Jenkins speaks to ABC Local Radio (ABC News)

Until this morning, the department's website was forecasting conditions would be good.

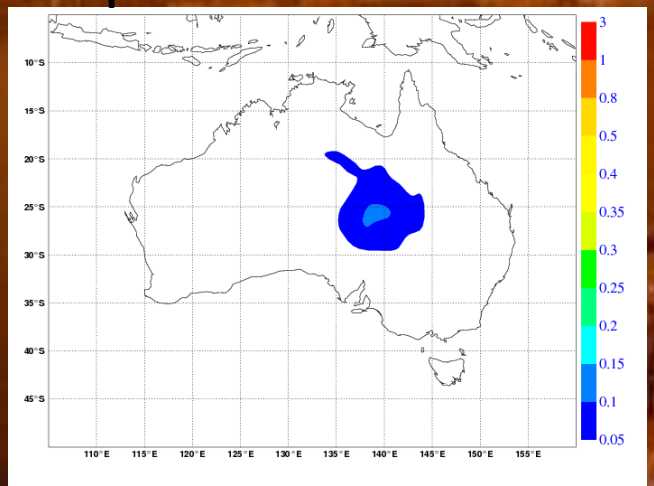


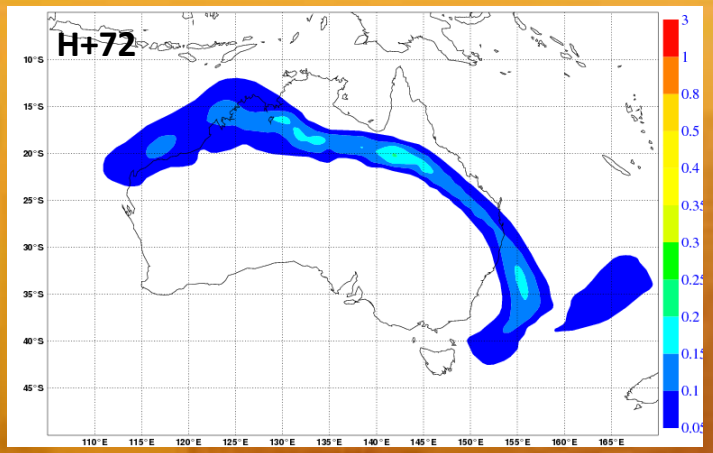
Sydney dust storm, 23-09-09

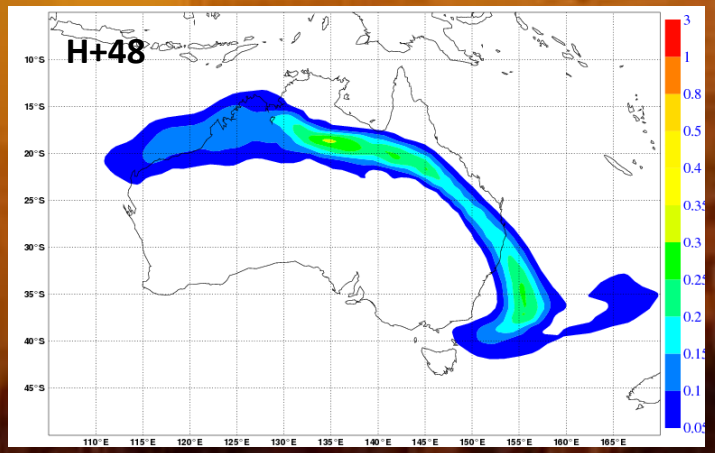


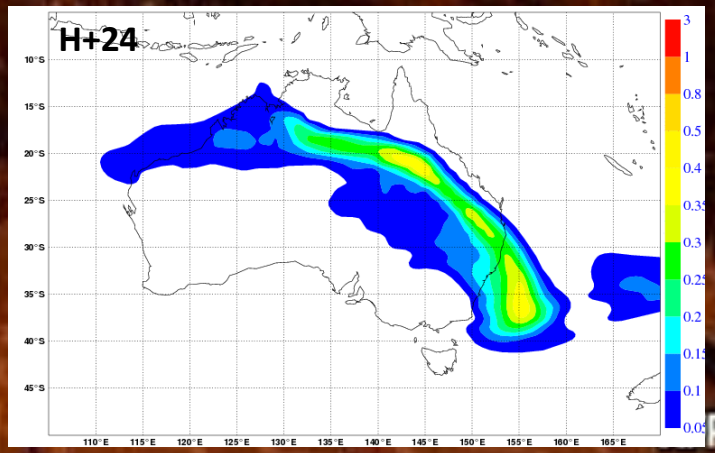
- A cold front combined with strong winds whipped up topsoil from the dried-out Lake Eyre basin and swept across New South Wales spreading about 600km along the east coast

Aerosol optical depth for desert dust: monthly average for September 2008





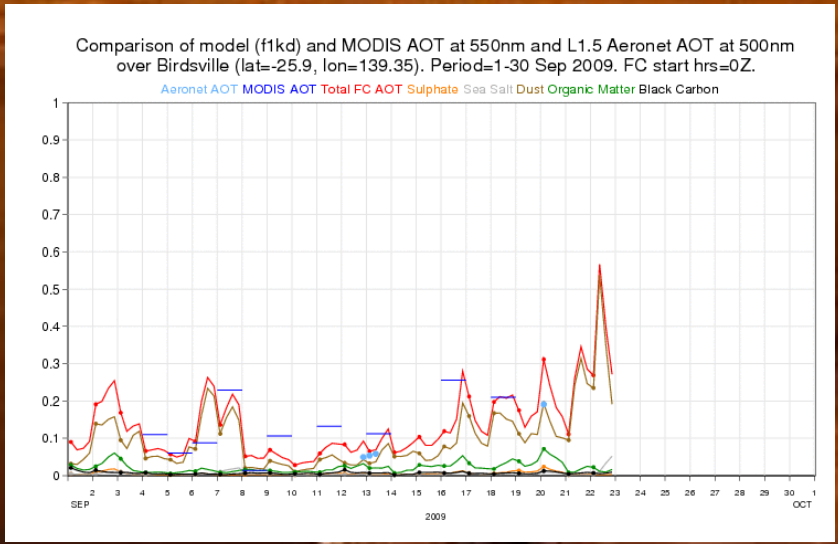


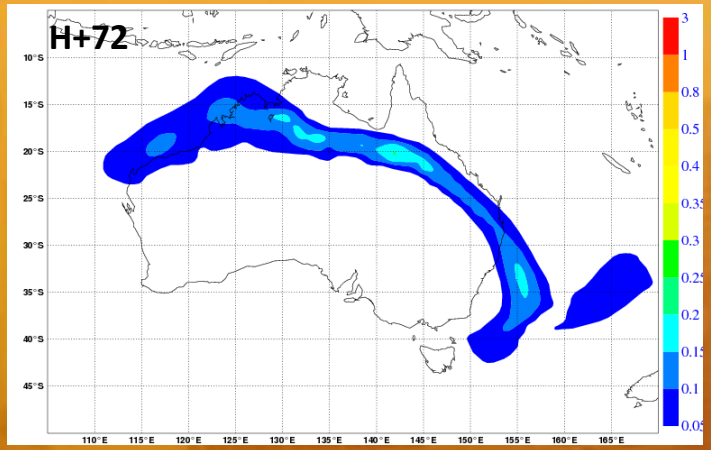


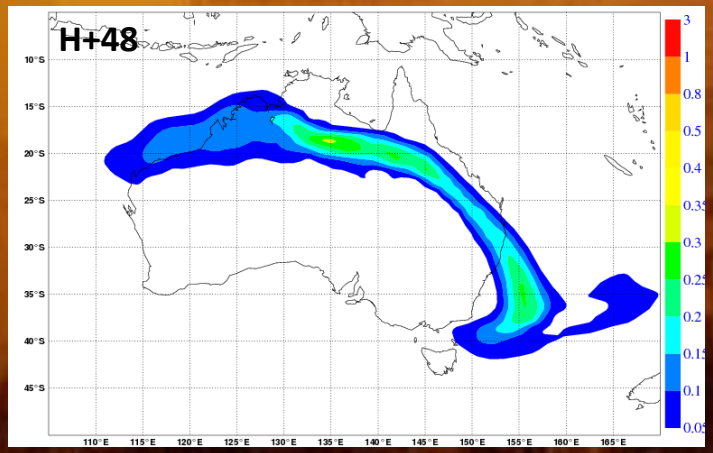
Sydney dust storm, 23-09-09

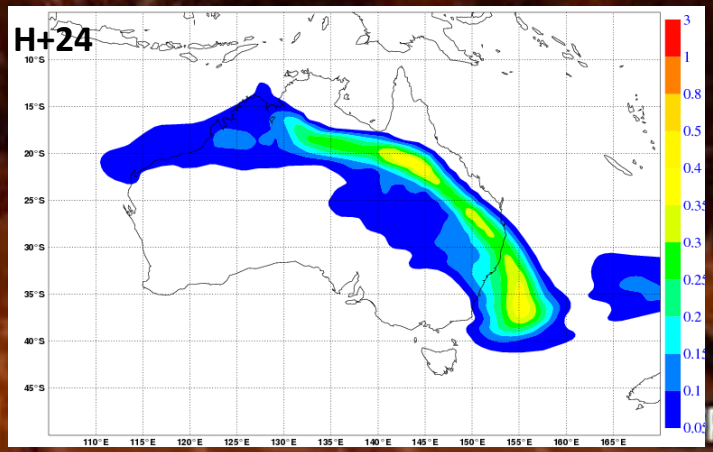
- A cold front combined with strong winds whipped up topsoil from the dried-out Lake Eyre basin and swept across New South Wales spreading about 600km along the east coast

Verification using AERONET data from Birdsville

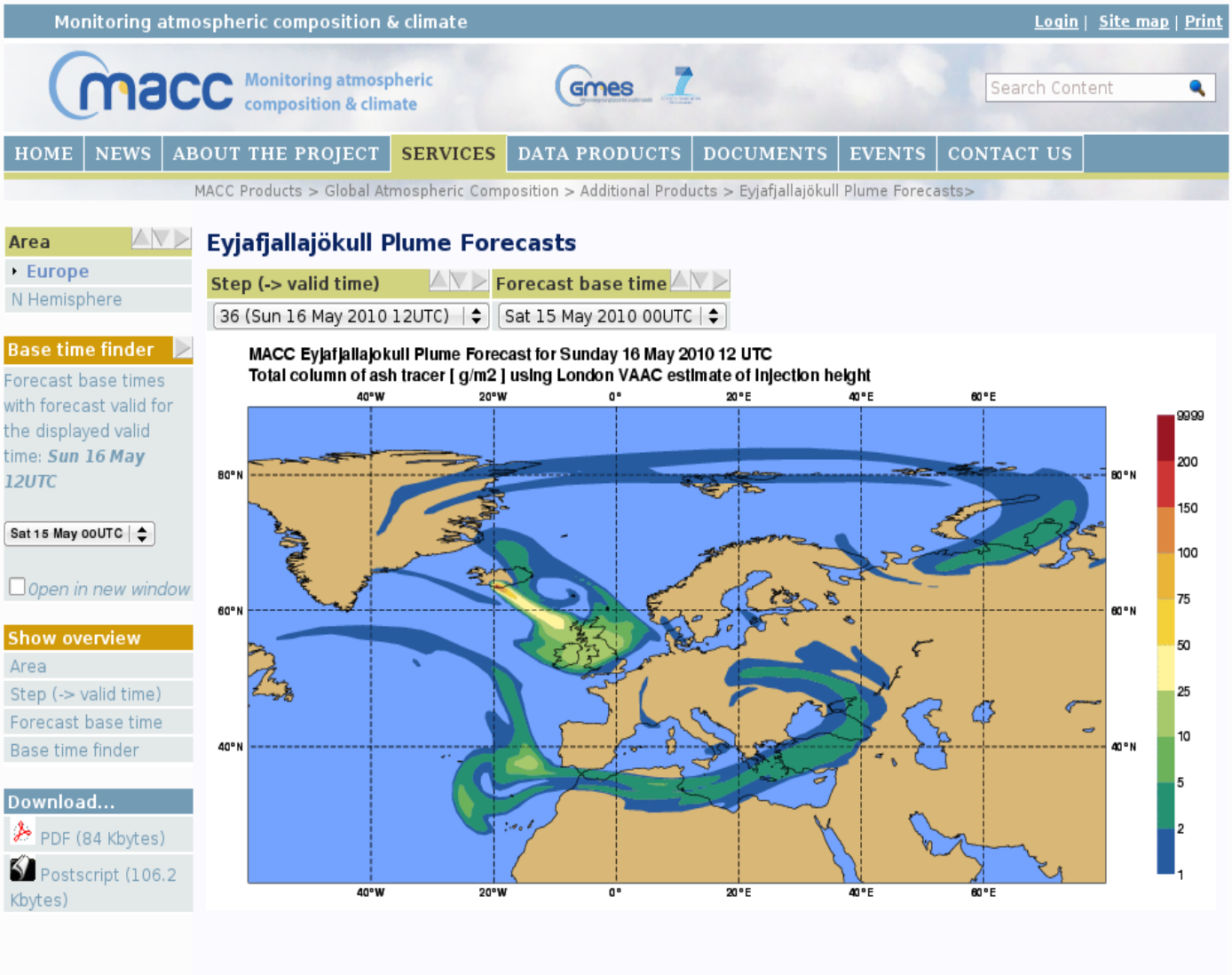






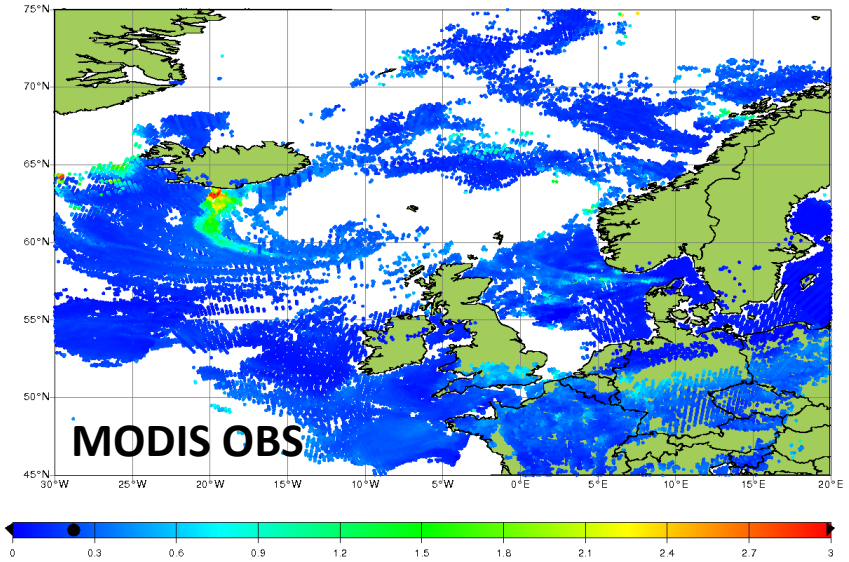


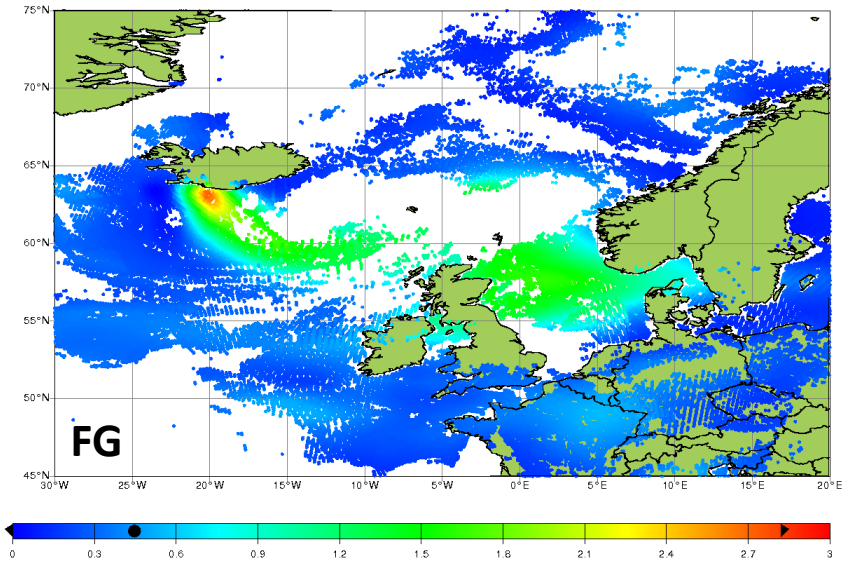
Daily MACC forecasts: Eyjafjallajökull eruption

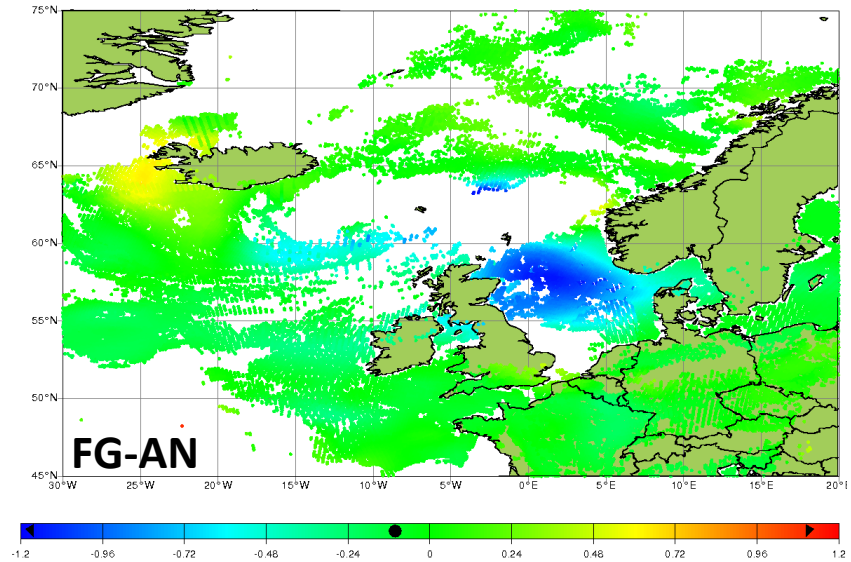


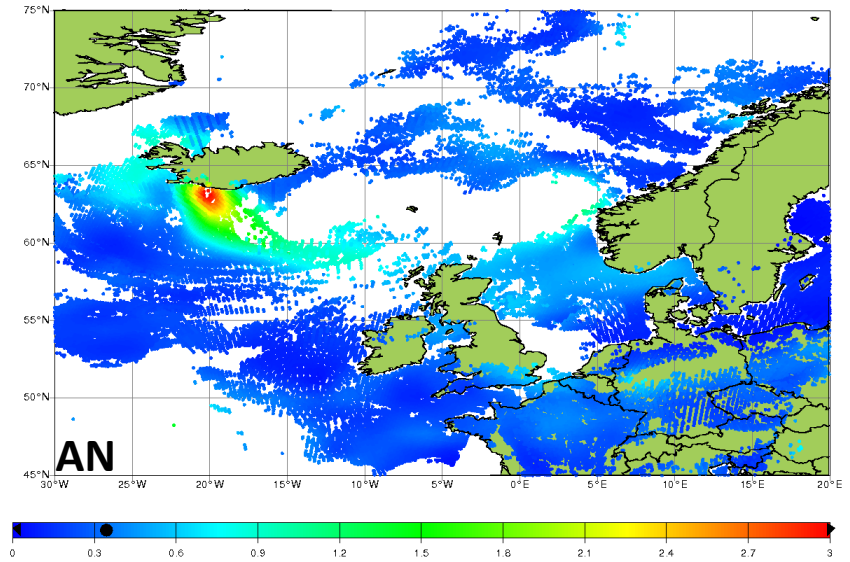
The global MACC system at ECMWF provided daily 4-day forecasts of the plume **shape** based on basic assumptions for the injection height and mass.

Aerosol Assimilation

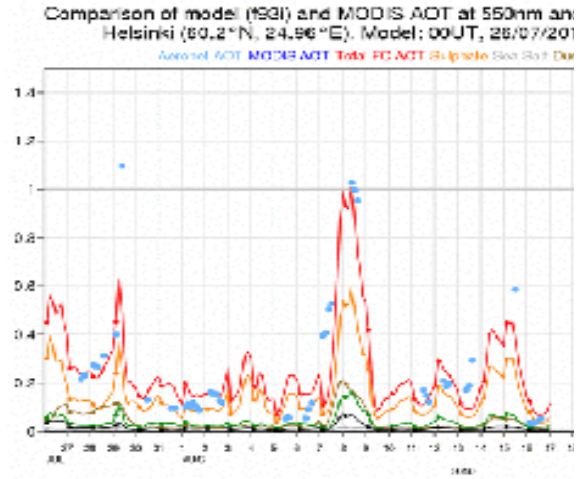


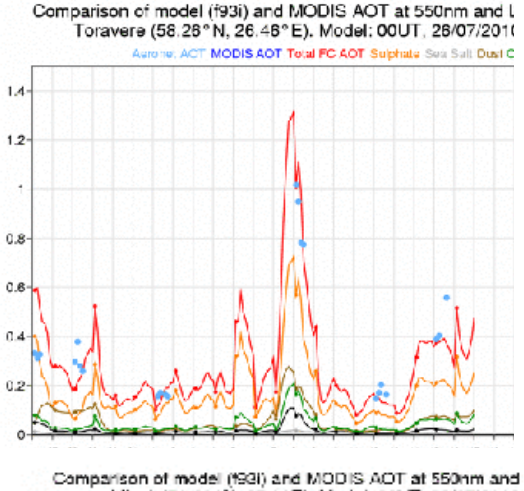


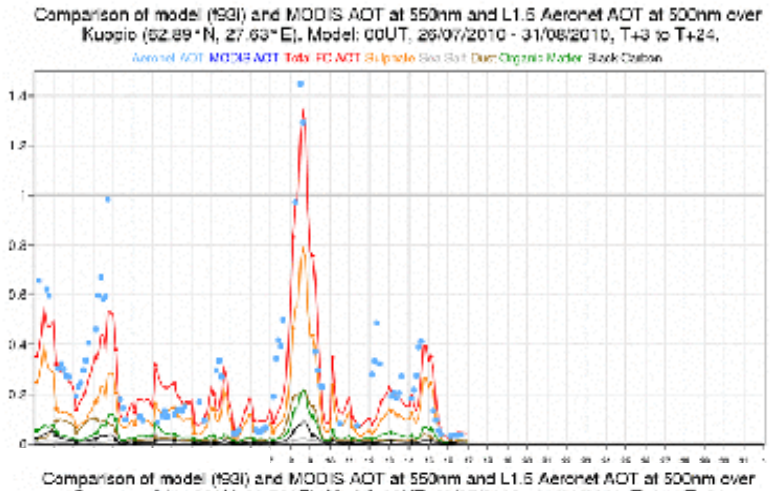


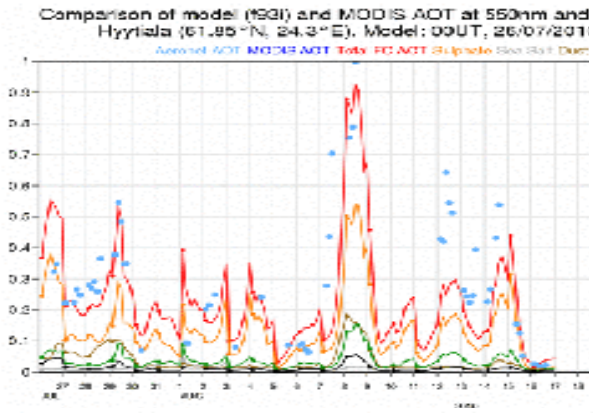


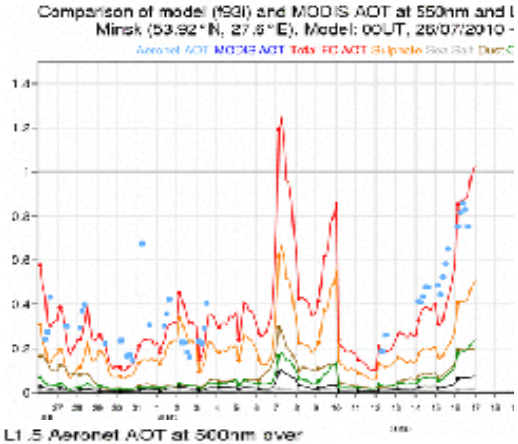
Russian fires, August 2010

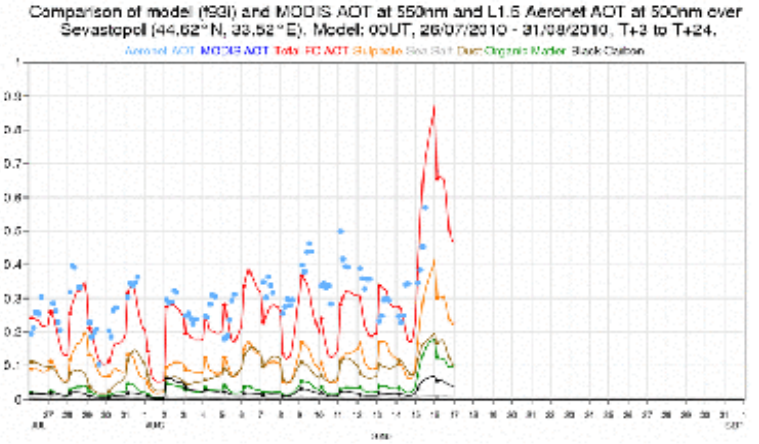












The MACC-AERosol system, assimilating MODIS tau550 allowed a very good description of the impact of the Russian fires In mid-August 2010 over North-Eastern Europe

In terms of optical depth, not speciation

(3) Dual aerosol control variable

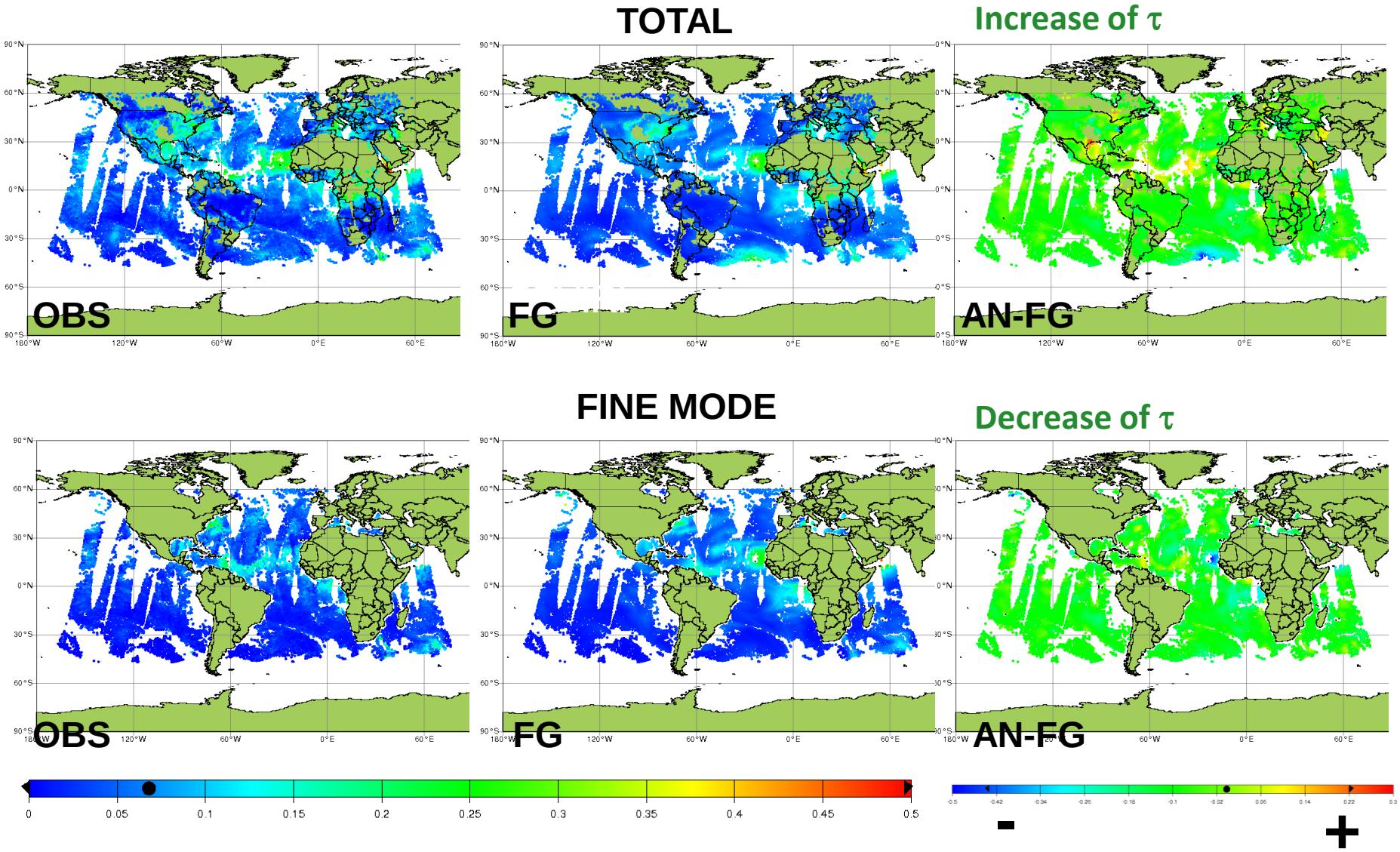
• Two control variables for aerosols: fine mode aerosol mixing ratio (defined as the sum of the first bin of sea-salt, first bin of desert dust, black carbon, organic matter, and SO4) and coarse mode aerosol mixing ratio (two largest bins of sea-salt and desert dust). Background error statistics are calculated using the NMC method.

• MODIS observations of fine AOD are included in the assimilation (over ocean only).

• Total AOD is also used to constrain both fine and coarse aerosol mixing ratios while fine mode AOD only constrains the fine mode.

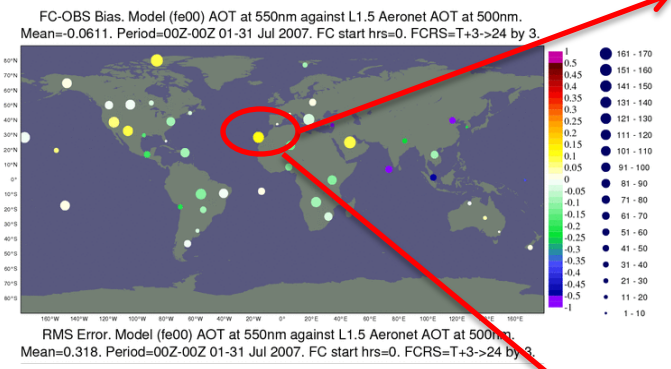
• Correlations between the two control variables are not accounted for – work in progress, plans to put a “balance” operator for aerosol mixing ratio.

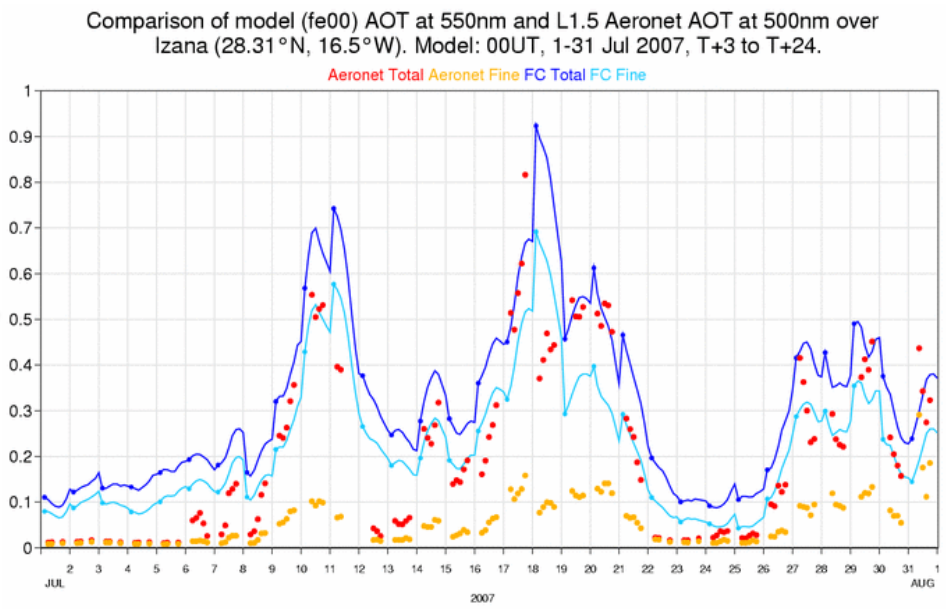
Assimilation of MODIS fine mode aerosol optical depth (July 2007)



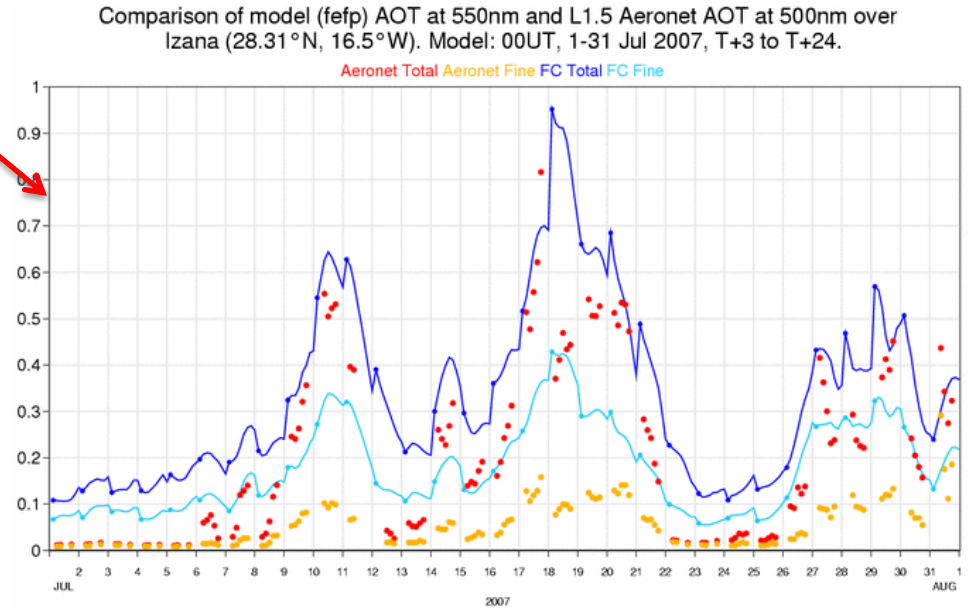
Dual CV is working fine: observations are able to “pull” in different directions fine and total AOD in areas of (known) model problems (i.e. off the coast of the Sahara)

AERONET verification (July 2007)



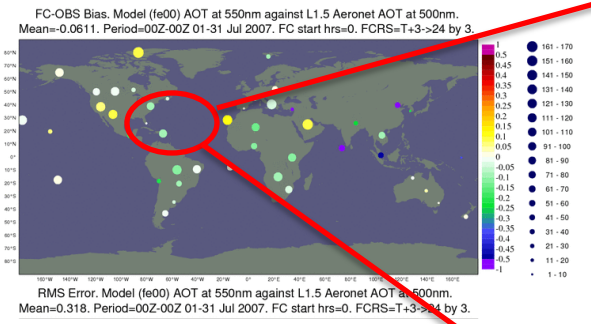


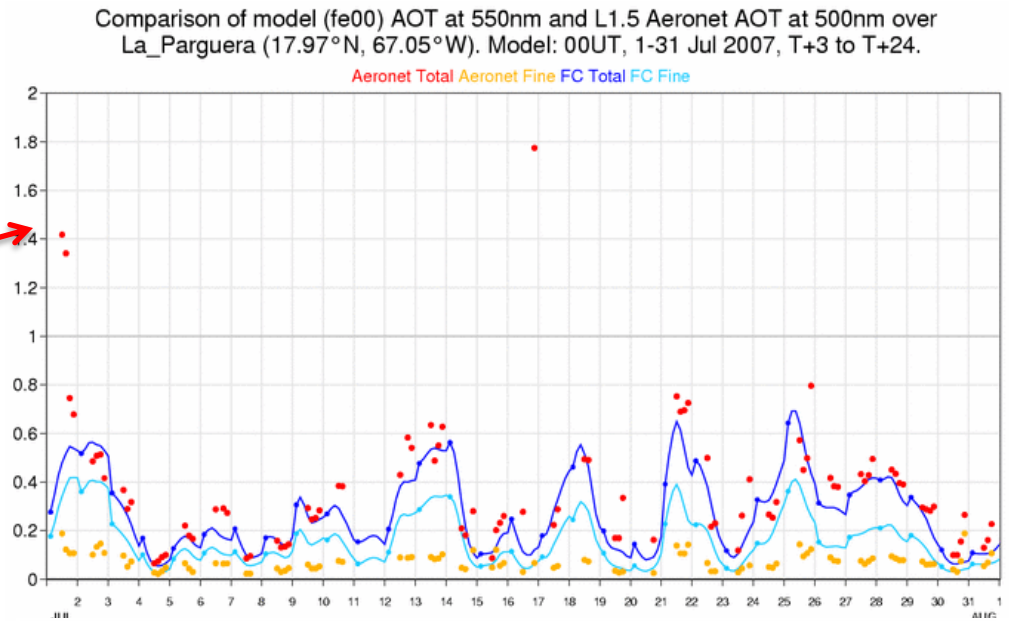
Single CV



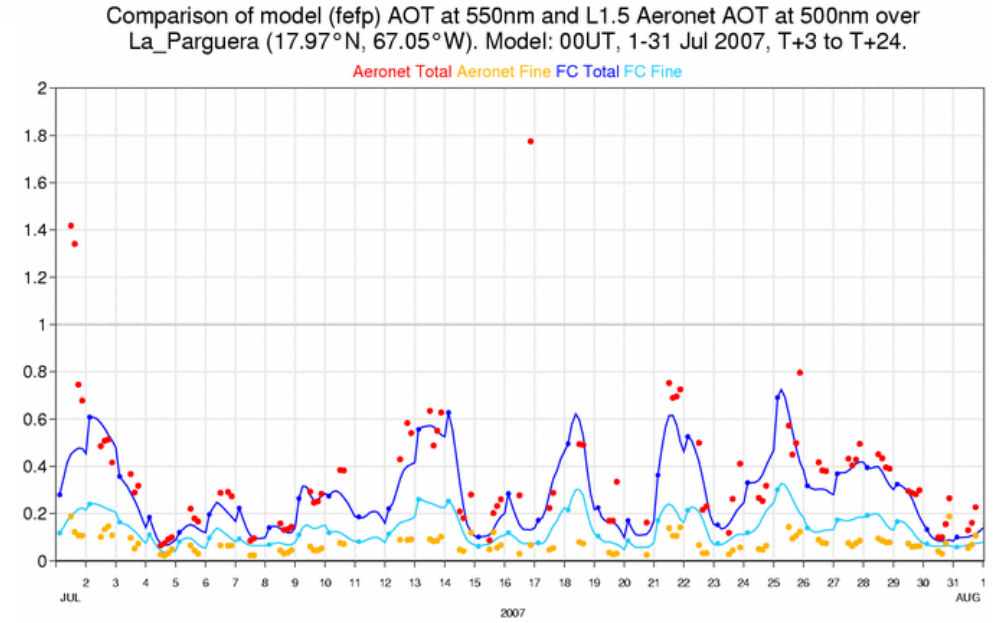
Dual CV

AERONET verification (July 2007)



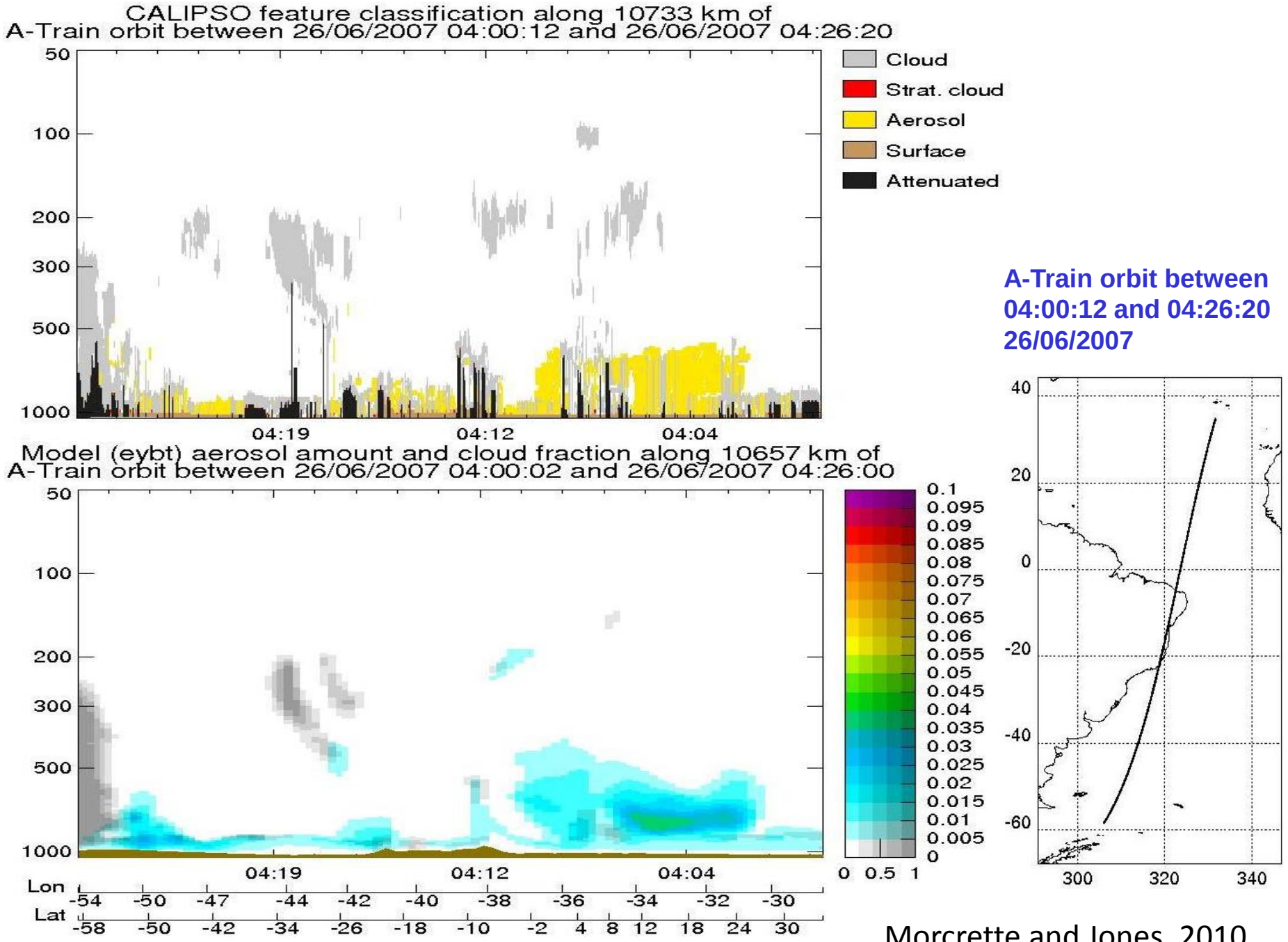


OLD

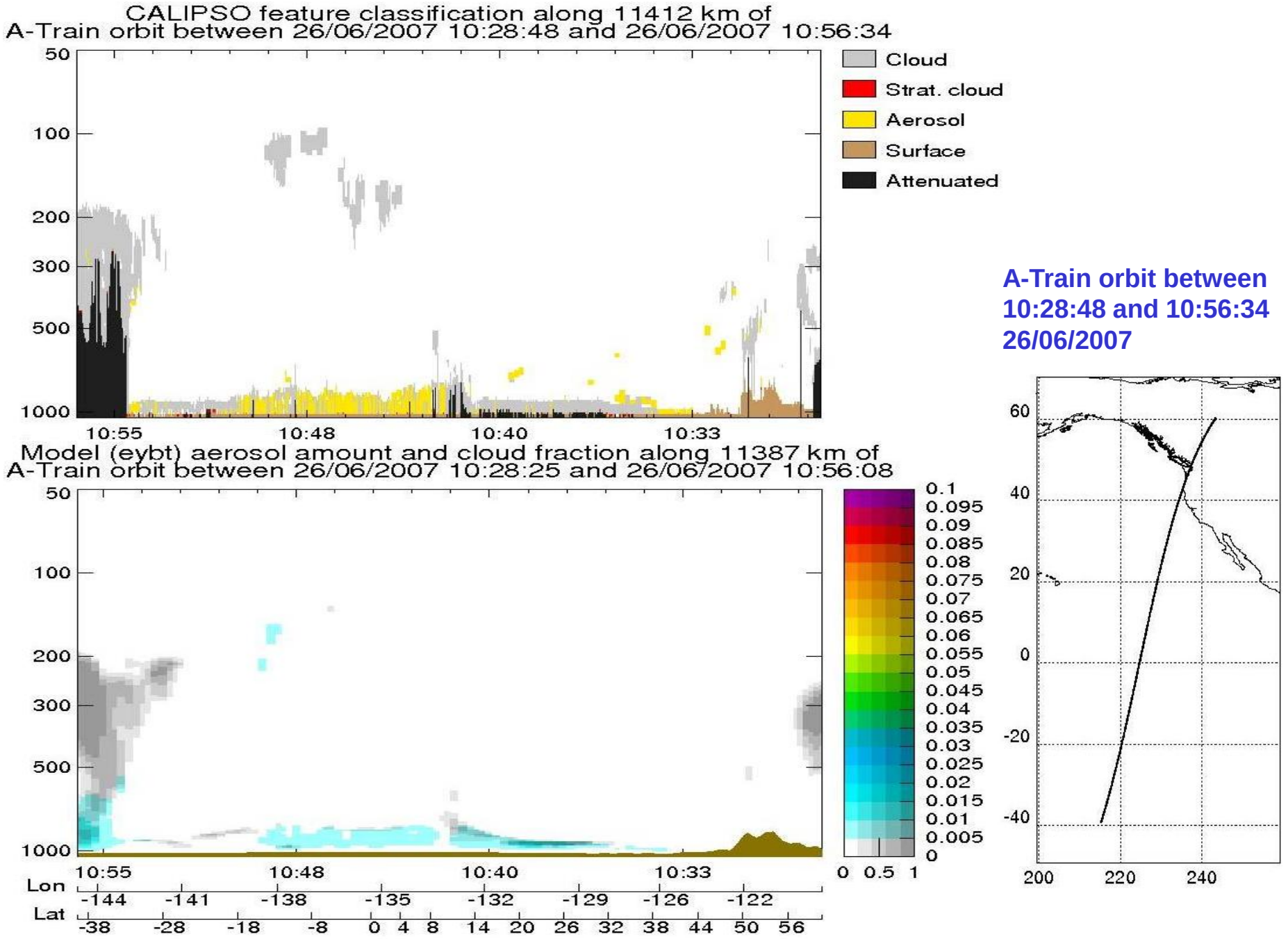


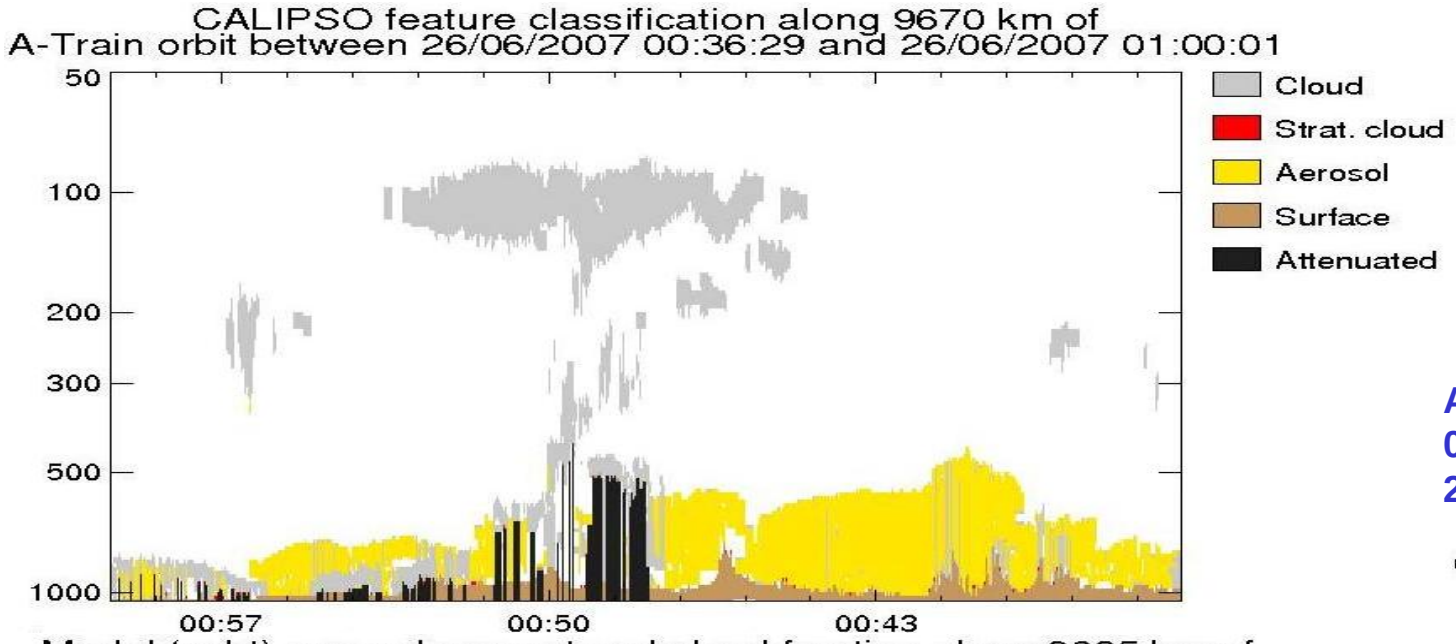
NEW

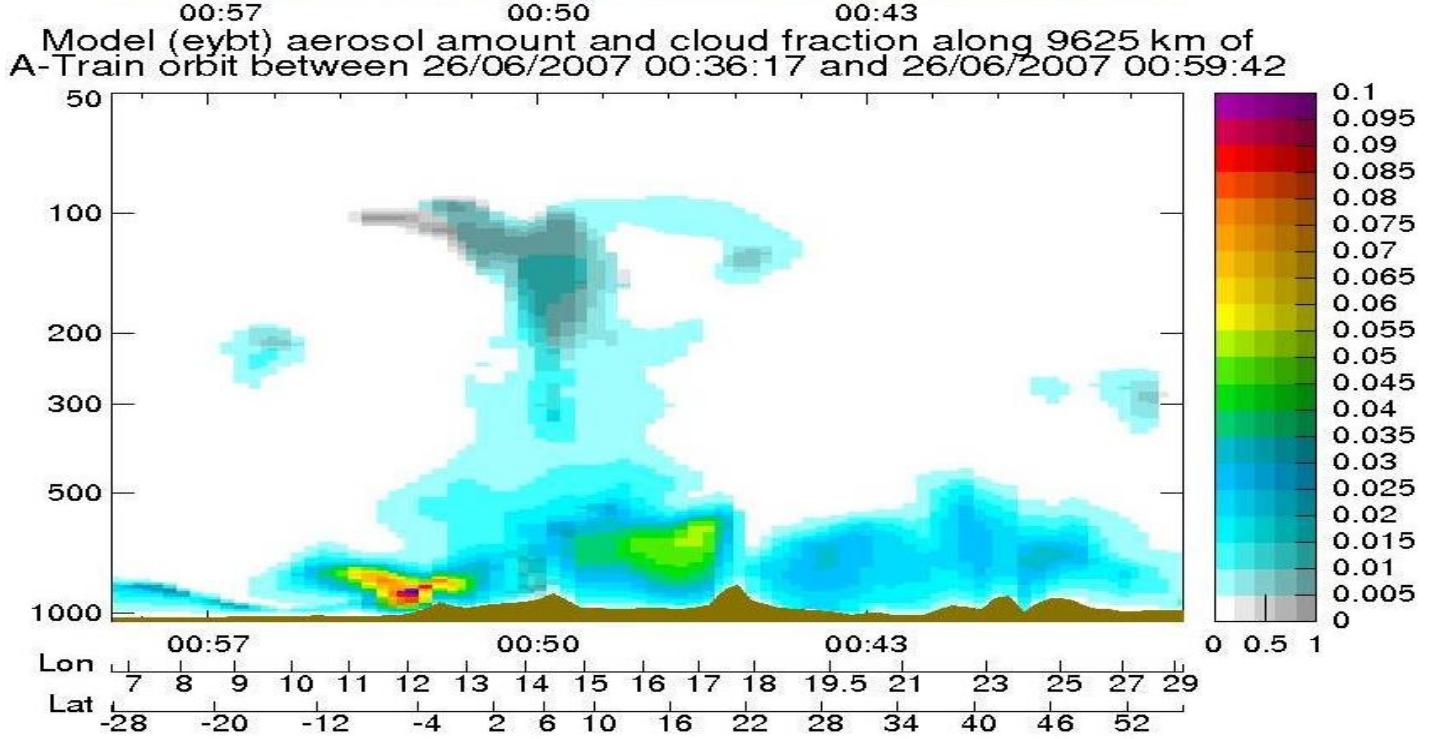
Thanks to Luke Jones



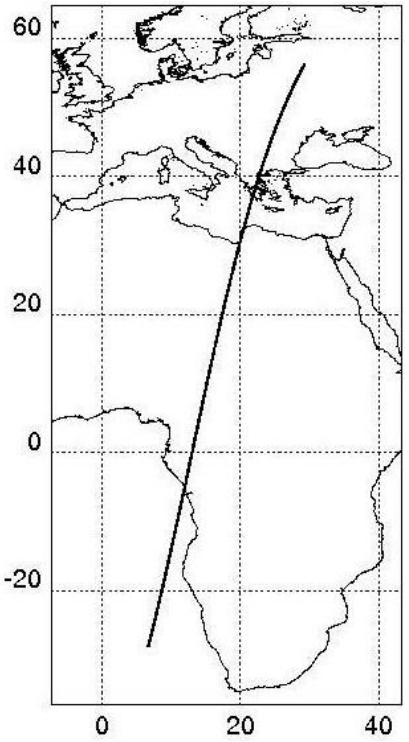
Morcrette and Jones, 2010


CALIPSO feature classification along 11412 km of
A-Train orbit between 26/06/2007 10:28:48 and 26/06/2007 10:56:34
Cloud
Strat. cloud
Aerosol
Surface
Attenuated
50
100
200
300
500
1000
10:55
10:48
10:40
10:33
Model (eybt) aerosol amount and cloud fraction along 11387 km of
A-Train orbit between 26/06/2007 10:28:25 and 26/06/2007 10:56:08
0.1
0.095
0.09
0.085
0.08
0.075
0.07
0.065
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0 0.5 1
Lon
-144 -141 -138 -135 -132 -129 -126 -122
Lat
-38 -28 -18 -8 0 4 8 14 20 26 32 38 44 50 56
A-Train orbit between
10:28:48 and 10:56:34
26/06/2007
60
40
20
0
-20
-40
200
220
240

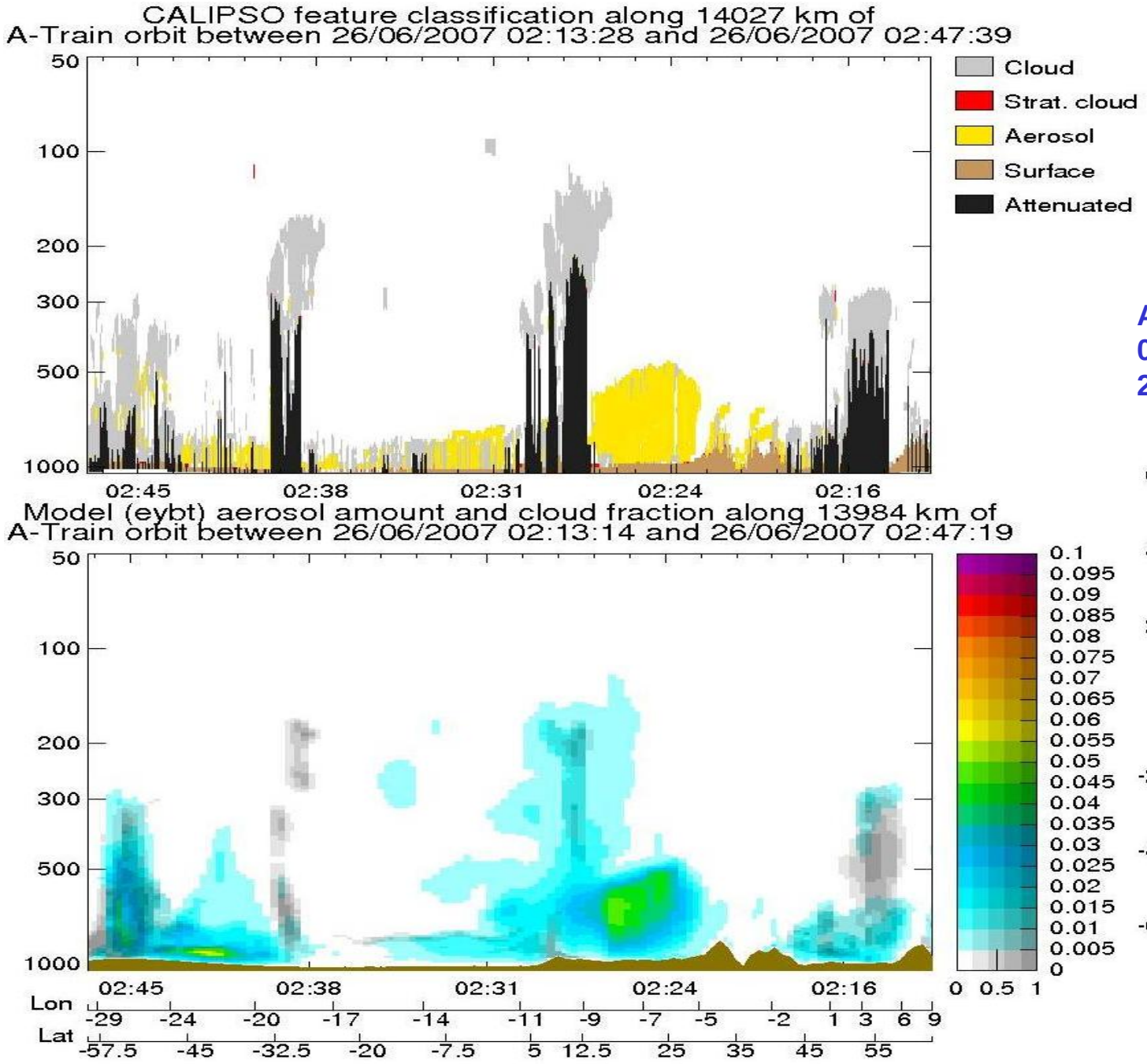




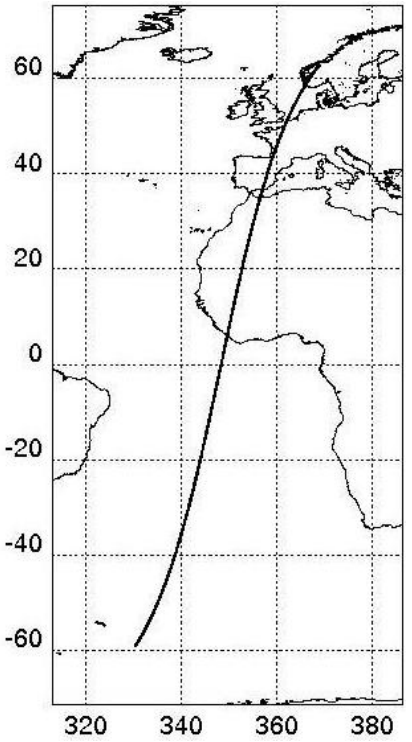
A-Train orbit between 00:36:29 and 01:00:01 26/06/2007



Aerosols transported upward by convection in ITCZ: realistic?



A-Train orbit between 02:13:28 and 02:47:39 26/06/2007



(4) Comparison of aerosol with CALIPSO cloud/aerosol mask: Conclusions

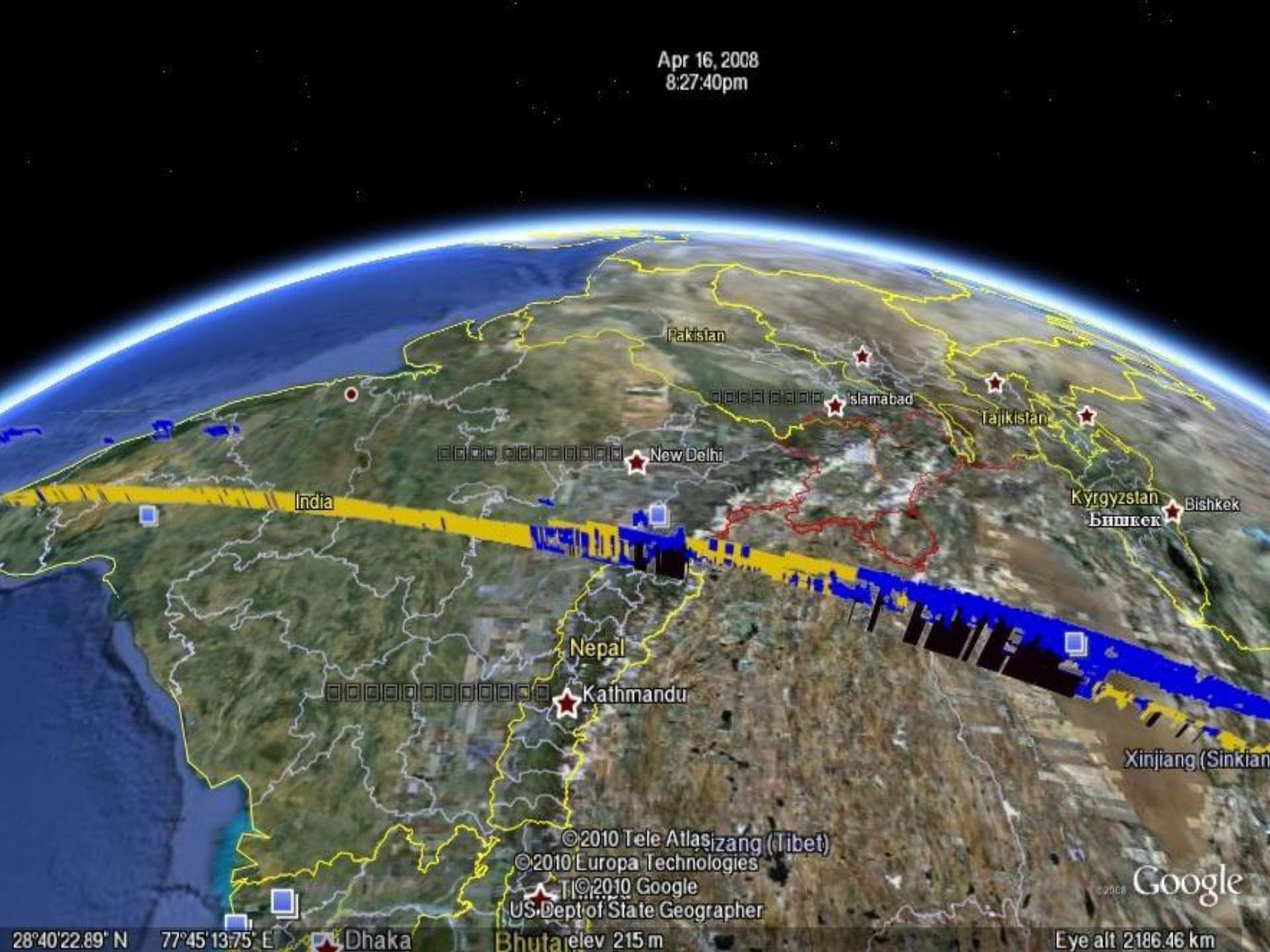
- From this limited set of comparisons, the vertical distribution of the model aerosols appears reasonable (although issue with convective transport)
- Deficiencies are often linked to limited knowledge of emissions of anthropogenic aerosols
- On the model side, the absence of a plume model for emission (for OM, BC, and SU) is likely to limit the extent of the area over which these aerosols might be simulated.
- CALIPSO cloud/aerosol mask is aerosol or cloud, whether model results often show aerosols within cloud layers

- **Next stage:**
  - Simulate the lidar signal at 532 nm from CALIPSO from the model
  - Possibly simulate the lidar signal at 355, 532 and 1064 nm and compare with some EARLINET observations

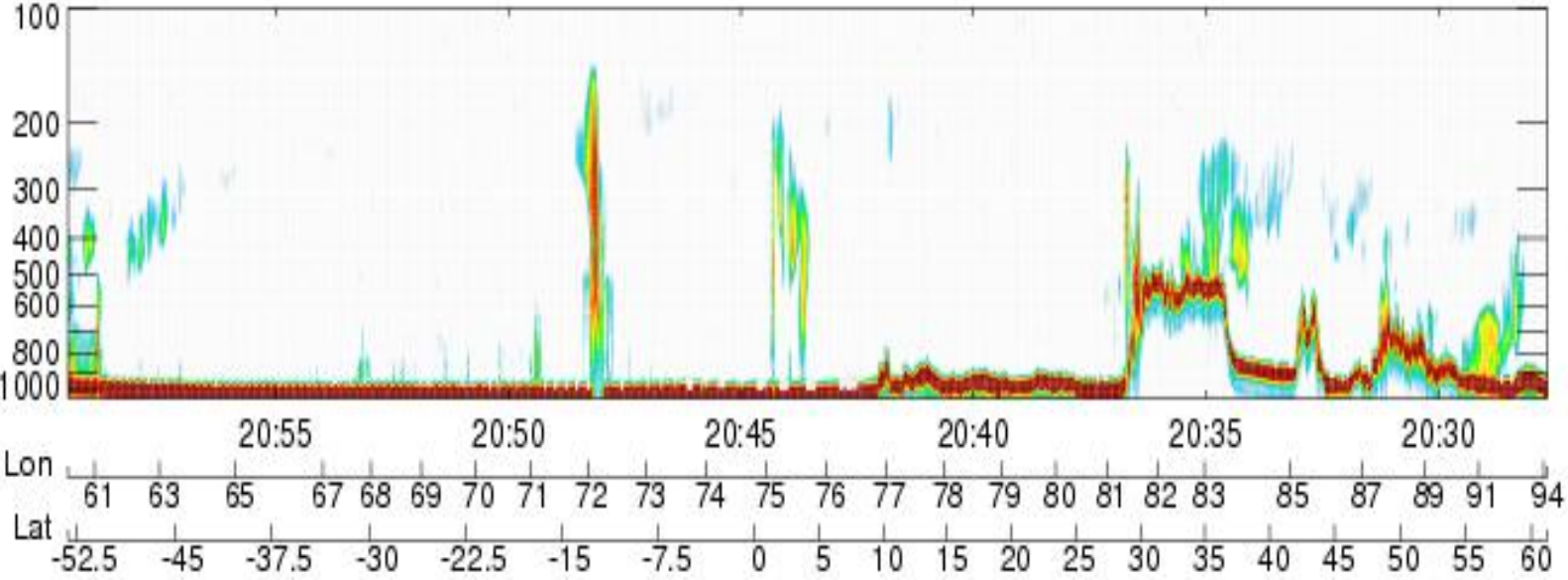
Preliminary results

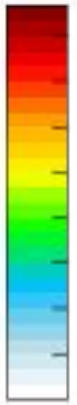
- The simulation of aerosols and associated lidar signal (LS) has been carried out for some dates in April 2008 using the IFS model at T_L511 L91.
- Results are shown for lidar signal from TOA at 532 nm.

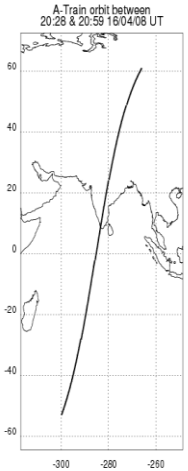
- Signature of various aerosols appears in difference of LS at different wavelengths.
- Similar simulations are now being done for lidar signal from surface stations (EARLINET).


Apr 16, 2008
8:27:40pm
Pakistan
Islamabad
Tajikistan
New Delhi
India
Kyrgyzstan
Бишкек
Bishkek
Nepal
Kathmandu
Xinjiang (Sinkian
©2010 Tele Atlas
©2010 Europa Technologies
©2010 Google
US Dept of State Geographer
Google
28°40'22.89" N
77°45'13.75" E
Dhaka
elev 215 m
Eye alt 2186.46 km

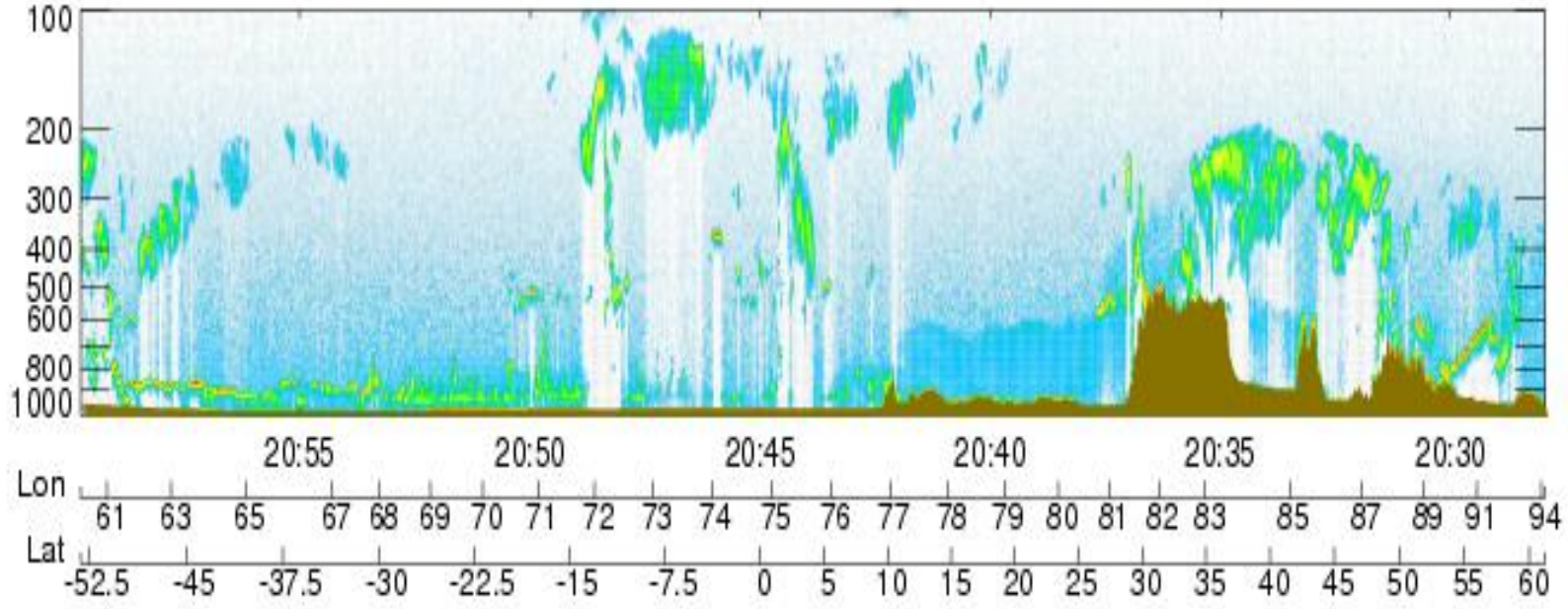
CloudSat reflectivity (dBZe) along 13058 km
of A-Train orbit between 20:27:40 & 20:59:28 16/04/08 UT

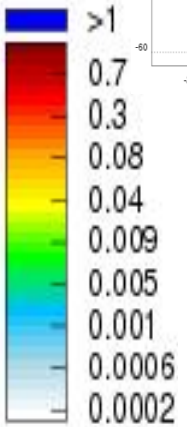


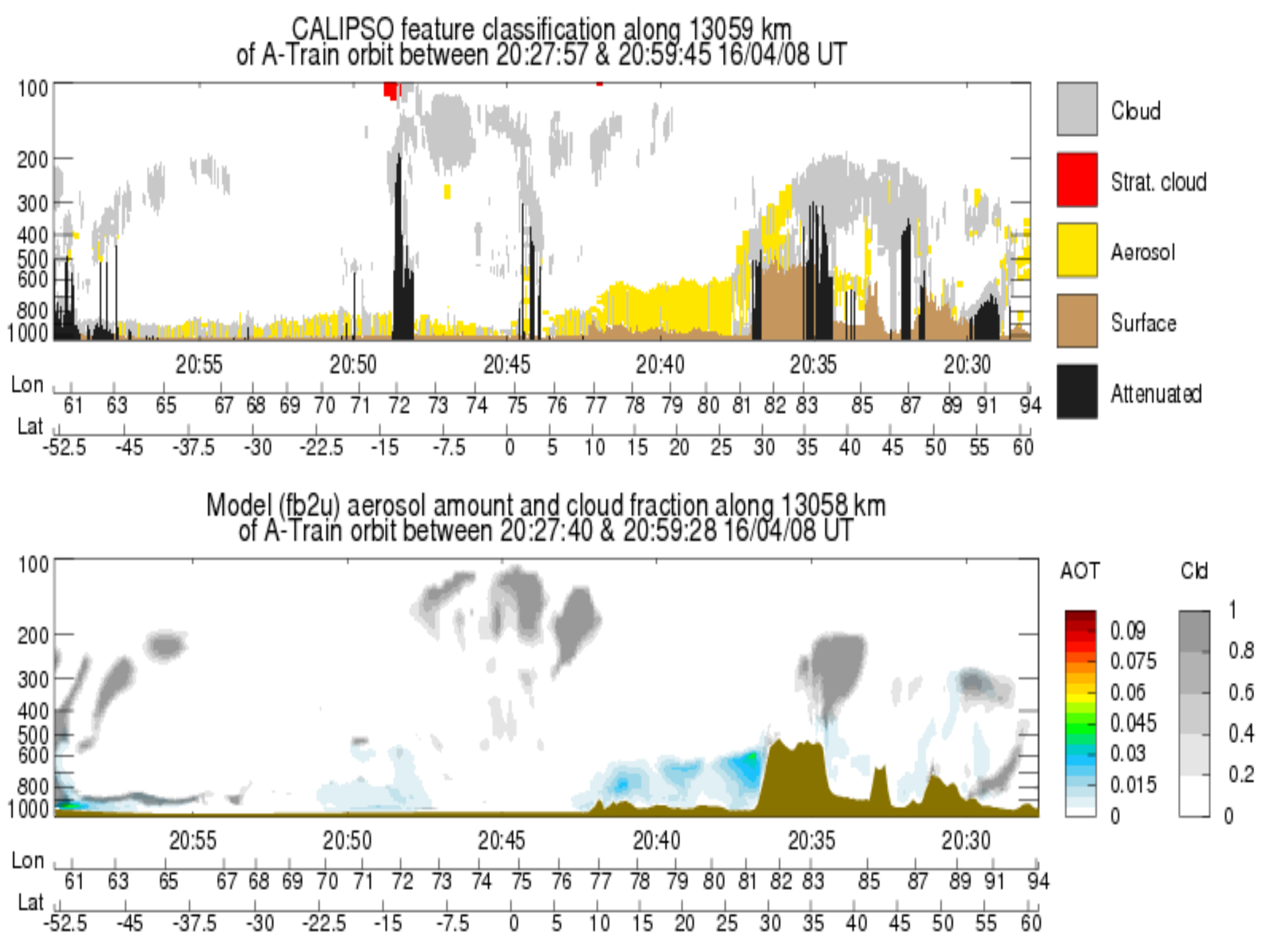


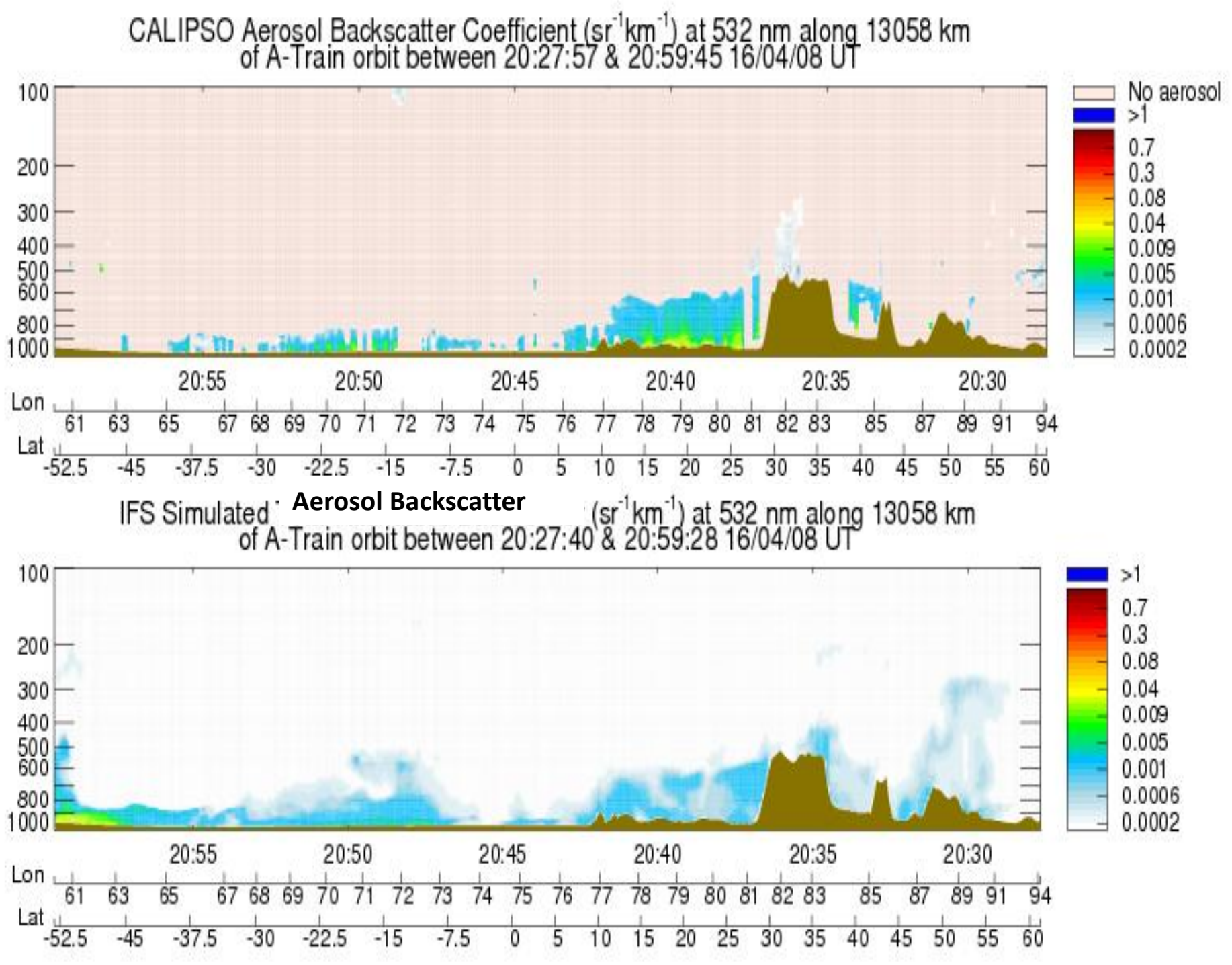


CALIPSO Total Attenuated Backscatter ($sr^{-1}km^{-1}$) at 532 nm along 13059 km
of A-Train orbit between 20:27:57 & 20:59:45 16/04/08 UT






CALIPSO feature classification along 13059 km
of A-Train orbit between 20:27:57 & 20:59:45 16/04/08 UT
100
200
300
400
500
600
800
1000
Cloud
Strat. cloud
Aerosol
Surface
Attenuated
20:55
20:50
20:45
20:40
20:35
20:30
Lon
61 63 65 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 85 87 89 91 94
Lat
-52.5 -45 -37.5 -30 -22.5 -15 -7.5 0 5 10 15 20 25 30 35 40 45 50 55 60
Model (fb2u) aerosol amount and cloud fraction along 13058 km
of A-Train orbit between 20:27:40 & 20:59:28 16/04/08 UT
AOT
0.09
0.075
0.06
0.045
0.03
0.015
0
Cld
1
0.8
0.6
0.4
0.2
0


CALIPSO Aerosol Backscatter Coefficient (sr-1km-1) at 532 nm along 13058 km
of A-Train orbit between 20:27:57 & 20:59:45 16/04/08 UT
No aerosol
>1
0.7
0.3
0.08
0.04
0.009
0.005
0.001
0.0006
0.0002
100
200
300
400
500
600
800
1000
20:55
20:50
20:45
20:40
20:35
20:30
Lon
61 63 65 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 85 87 89 91 94
Lat
-52.5 -45 -37.5 -30 -22.5 -15 -7.5 0 5 10 15 20 25 30 35 40 45 50 55 60
Aerosol Backscatter
IFS Simulated
(sr-1km-1) at 532 nm along 13058 km
of A-Train orbit between 20:27:40 & 20:59:28 16/04/08 UT
>1
0.7
0.3
0.08
0.04
0.009
0.005
0.001
0.0006
0.0002
100
200
300
400
500
600
800
1000
20:55
20:50
20:45
20:40
20:35
20:30
Lon
61 63 65 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 85 87 89 91 94
Lat
-52.5 -45 -37.5 -30 -22.5 -15 -7.5 0 5 10 15 20 25 30 35 40 45 50 55 60

(6) 1D-Var for CALIPSO aerosol observations

Observations :

- CALIPSO backscatter 532 nm data (version 2009Q3)
- pre-processing data:
  - cloud screening using CALIPSO level 2, 1 and 5 km cloud top heights *(no data used below highest cloud top)*
  - averaging backscatter to model grid boxes

Observation errors :

- set to 25% of observation value (acceptable for feasibility studies)

Observation operators :

- clear sky aerosol retrievals based on developed forward operator *(Morcrette et al., 2009)*
- considering extinction and backscatter from 11 aerosol species, gaseous extinctions as well as temperature and pressure dependencies of these processes

Model data (first guess):

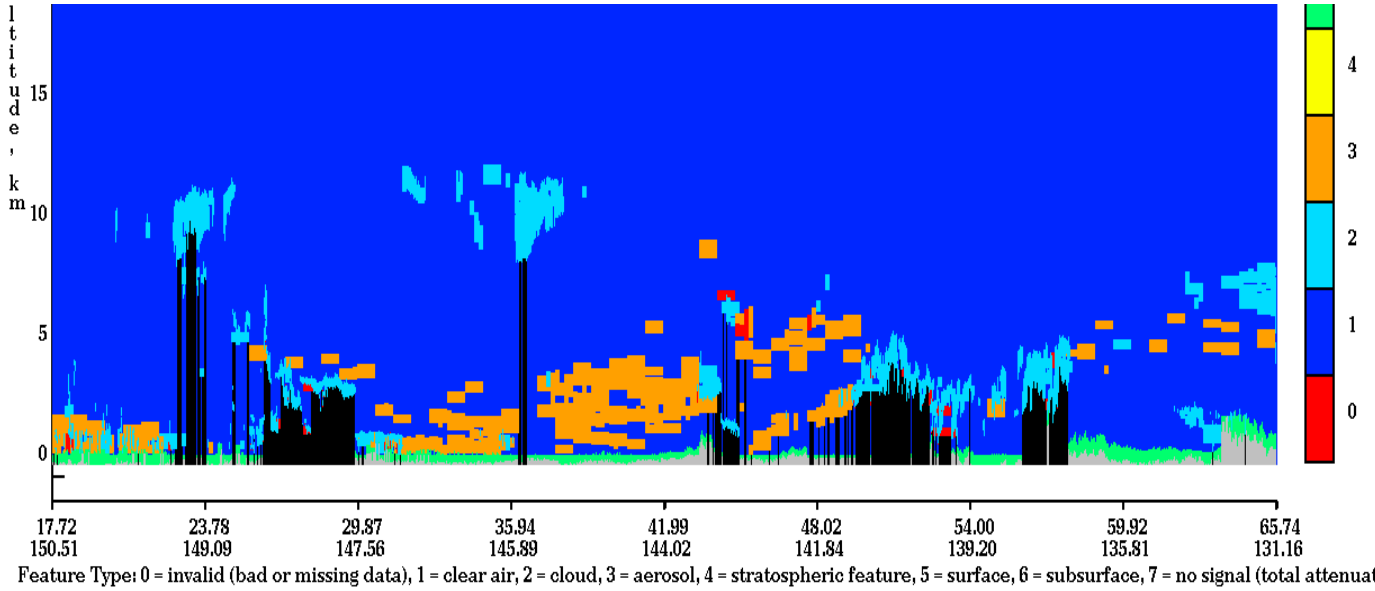
- 11 aerosol species ***(3 sea salt, 3 dust, organic/black carbon, hydrophilic/hydrophobic, sulphate)***
- temperature, humidity, ozone, surface pressure

Model error statistics :

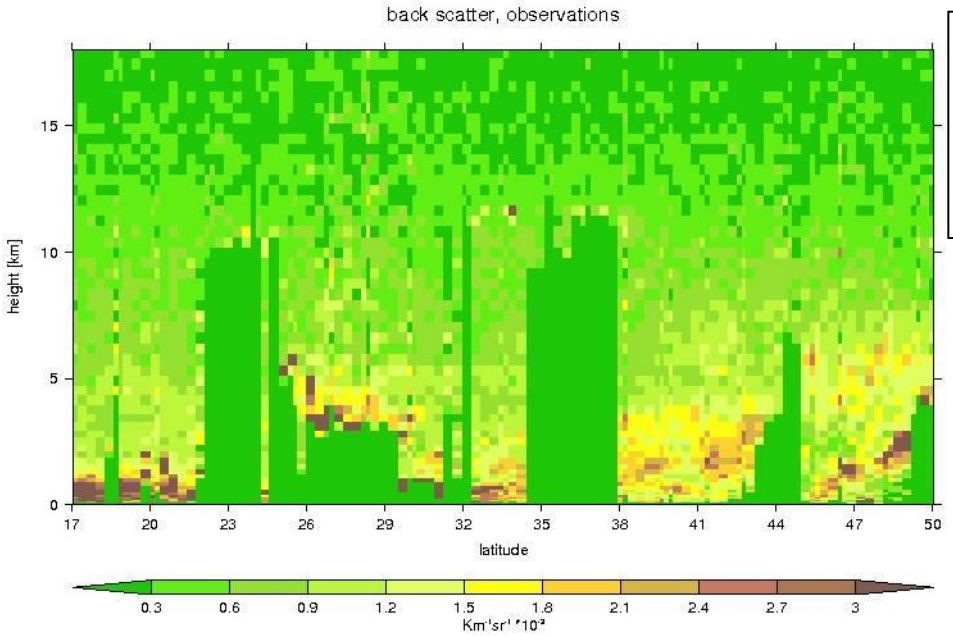
- generated from GEMS near real time experiments data via the NMC method
- 60-level data linearly interpolated to 91 levels

Janiskova, Stiller and Morcrette, 2010

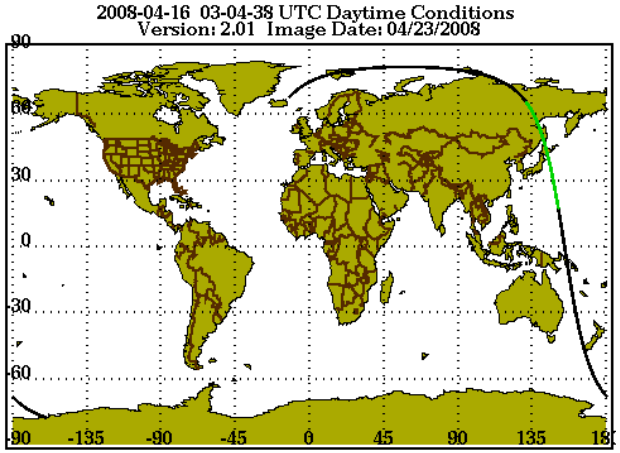
CALIPSO observations and cloud screening (1)



Please note CALIPSO Version “2009Q3”



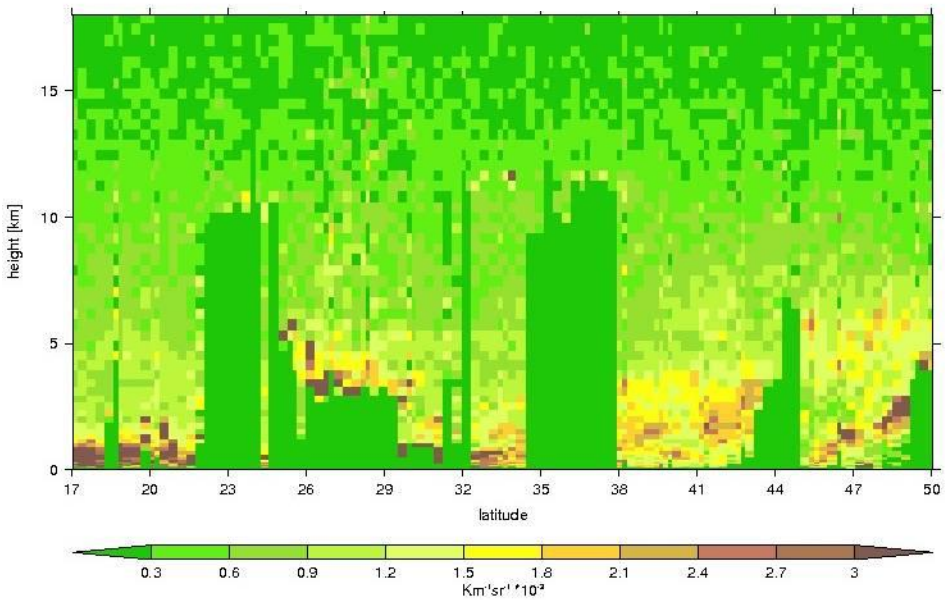
Cloud screening: 5km product



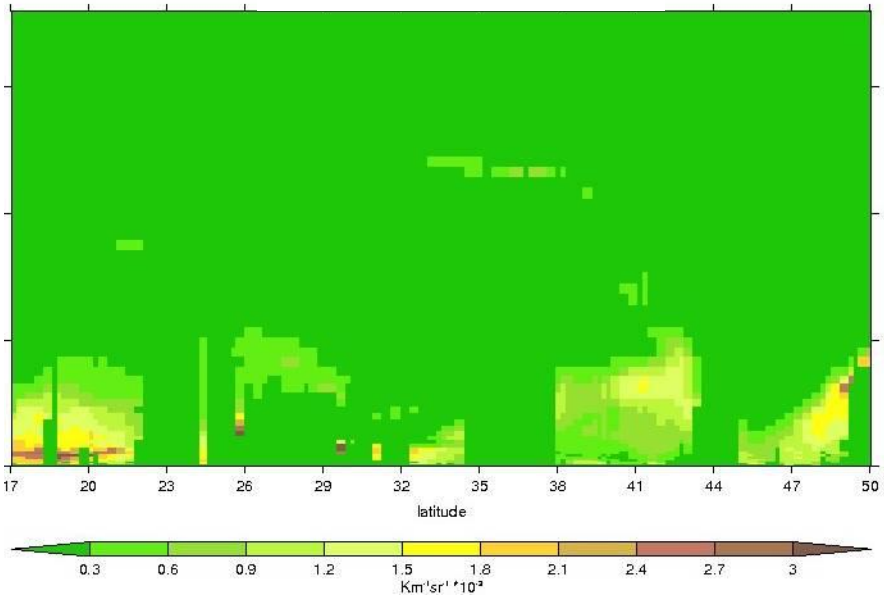
Case 20080416

1D-Var for CALIPSO aerosol observations – FG vs. AN

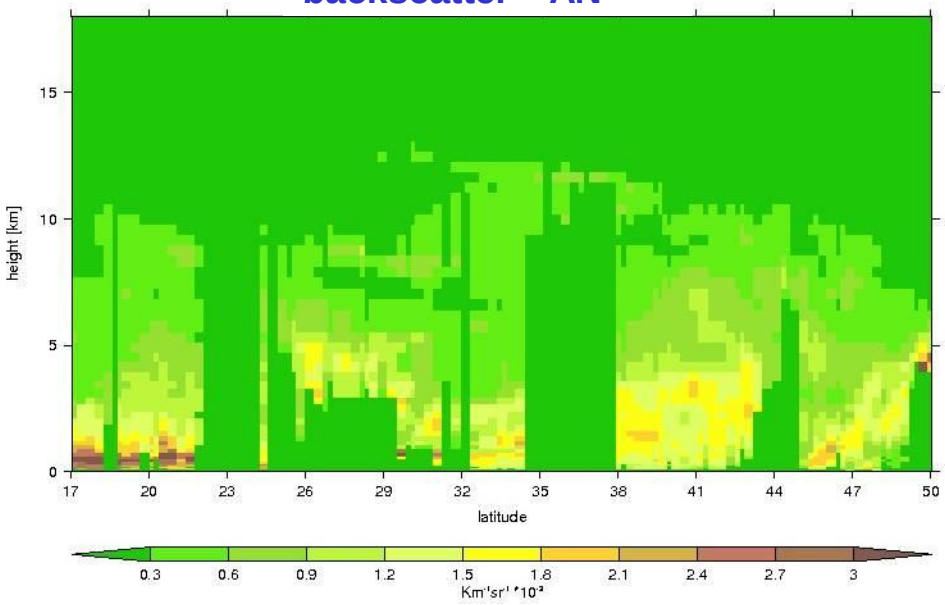
backscatter – OBS

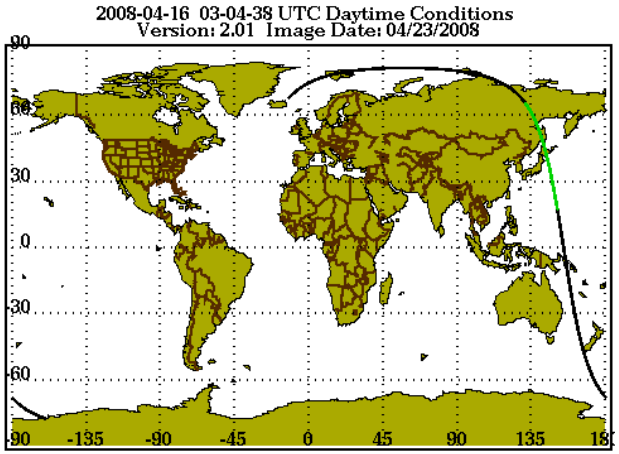


backscatter – FG



backscatter – AN





Case 20080416

Summary of 1D-Var experiments for aerosol observations

- A major technical and scientific development towards the assimilation of aerosol information from CALIPSO has been implemented

- Main outcomes from 1D-Var experimentation:
  - model equivalent aerosol observations are substantially driven towards CALIPSO backscatter data
  - model aerosols are strongly incremented
  - encouraging results suggest there is a potential of using these observations in the ECMWF aerosol system
  - further use in assimilation studies would require improved observation errors, more targeted cloud screening, …
  - exciting perspectives for air quality monitoring and forecasting

As a matter of conclusions

- As part of the GEMS/MACC projects, the development, validation and pre-operational provision of aerosol analyses and forecasts by the ECMWF IFS have relied heavily on the aerosol-related satellite data provided by MODIS, CALIPSO, and for verification on the surface measurements at the AERONET stations.

- These aerosol analysis and forecast (up to day 4) are now run with a TL255 L60 (~80 km) version of the IFS (operational model is TL1279 L91 (~16km)). Even so, the analysis products are starting to be widely used (in Europe) as boundary conditions for regional / limited area forecast models (7 countries as part of MACC)

- These analysis and forecast products are being refined through further aerosol and meteorological model developments, and will continue (for the years to come) to depend on the near-real time provision of such satellite (and surface) measurements.

- So, thank you for the A-Train …

- **And thank you for your attention**